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ABSTRACT

For many summers the Radiation Science and Engineering Center at Pennsylvania State University has been the site of a Nuclear Concepts and Technological Issues Institute for secondary school science teachers. As a culminating activity of the institute teachers develop lesson plans, laboratory experiments, demonstrations, or other activities and projects to take with them for use in their own science classrooms. This booklet contains 20 especially creative, unusual, or well designed projects selected from those devised by the teachers. The activities are designed for a wide range of grades and some involve group work, others are presented in various forms such as simulations, games, and puzzles. The booklet is divided into three sections: "Atomic Theory Made More Concrete"; "Radiation: Applications and Issues"; and "Using the Chart of the Nuclides." Appendices include additional activities and sources of materials and information. (JRH)

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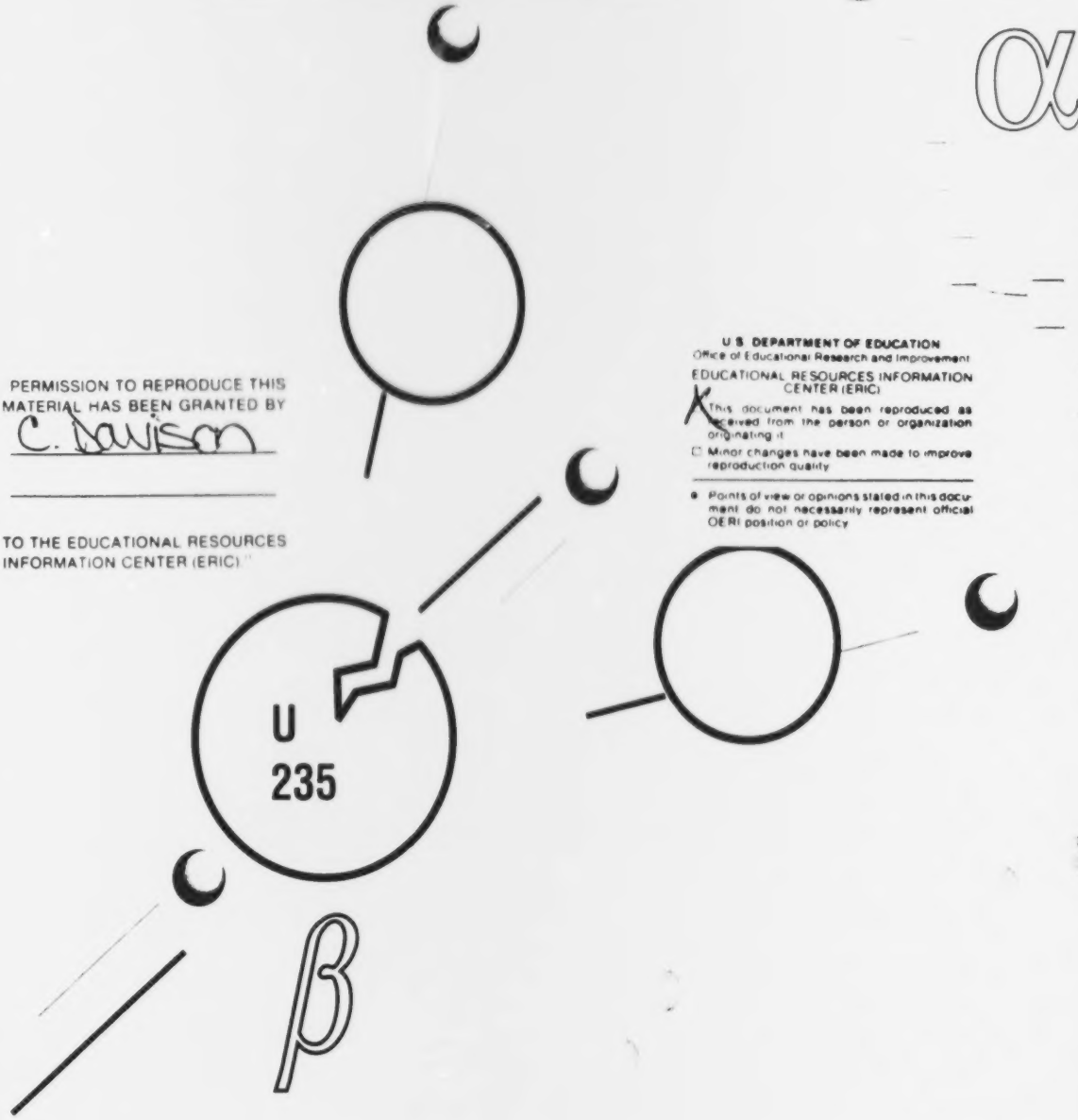

TEACHER ACTIVITY BOOKLET

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Nuclear Concepts &
Technological Issues
Institute

TEACHER ACTIVITY BOOKLET

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and
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Foreword

For many summers the Radiation Science and Engineering Center at Penn State has been the site of a Nuclear Concepts and Technological Issues Institute for secondary school science teachers. As a culminating activity of the institute teachers develop lesson plans, laboratory experiments, demonstrations, or other activities and projects to take with them for use in their own science classrooms.

This booklet contains twenty especially creative, unusual, or well designed projects selected from those devised during recent summers, with the hope that they may prove useful to other science teachers in their classrooms. Many of the activities are very simple and appropriate for various classes and grade levels. A few are more complex and therefore better suited to upper level or advanced science classes. Some activities may be done individually in class or at home; others require cooperation by one or more groups of students in order to obtain sufficient data to complete the project. Several interesting activities include simulations, games and puzzles.

We hope that the activities and projects included here will provide your students with some good hands-on and minds-on learning about nuclear concepts and associated technological and societal issues. For further information, ideas, suggestions, etc. please refer to Appendix A, Additional Activities and Appendix B, Sources of Materials and Information.

This material is based upon work supported in part by the National Science Foundation under Grant #TPE-9053806 Teacher Enhancement / Private Sector Partnerships program. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation or the industry sponsors. This project is endorsed by the American Nuclear Science Teachers Association.

We welcome your comments on the booklet as a whole and we will pass on your specific questions or suggestions to individual authors at your request. Please send your comments, questions, or request for additional copies to: Candace C. Davison, Nuclear Education Specialist and Senior Reactor Operator. Breazeale Reactor, The Pennsylvania State University, University Park, Pa 16802; telephone: 814-865-6351.

Table of Contents

Foreword

Atomic Theory Made More Concrete

Unit of Study on the Mathematical Treatment of Random Error 1

Lessons on Radioactivity Using the Learning Cycle Format 12

Beanium Lab 18

An Activity for Illustrating the Concepts of Atomic Mass and Mass Number 20

Half-Life Demonstration 23

Lab Illustrating Random Disintegration 25

The Ionization Potential of Argon 27

Researching Nuclear Scientists 30

Nuclear Crossword Puzzles 33

Radiation: Applications and Issues

Relating Radiometric Age Dating to Relative Age, Absolute Age and the Geologic Time Scale 41

An Investigation of Radiation and Food 43

The Effects of Radiation on Corn Seeds 48

Using Beta Radiation to Determine Thickness 50

Directed Reading and Thinking Activity 52

Low Level Radioactive Waste Activities 55

Radon Testing Activities for High School Science Classes 58

Using the Chart of the Nuclides

Chart of the Nuclides Worksheet 63

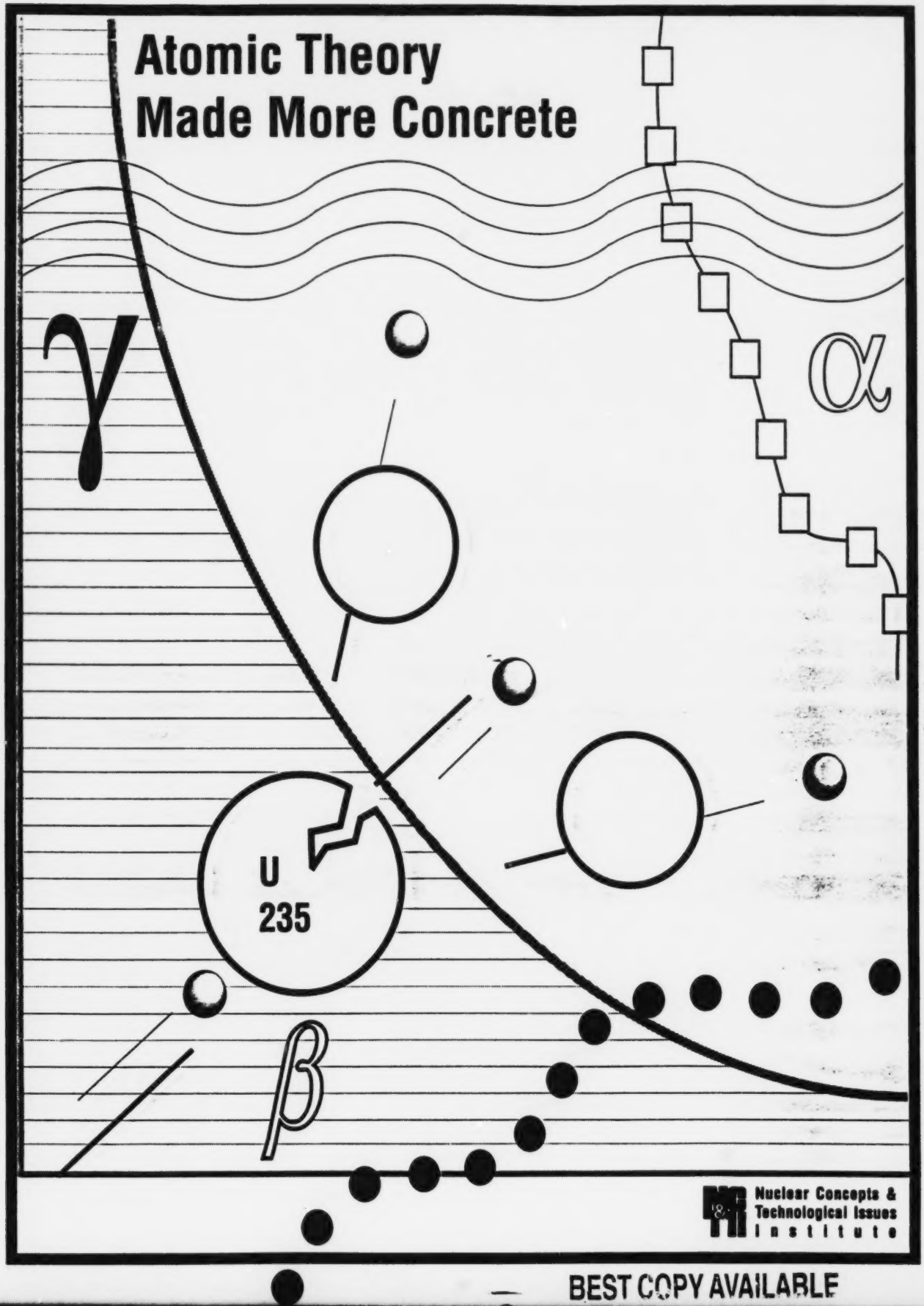
179 Ways to Make Gold 71

Captain Nuclide 84

Flip Book Chart of the Nuclides: The Uranium-238 Decay Chain 88

Appendix A: Additional Activities A1

Appendix B: Sources of Materials and Information B1



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Unit of Study on the Mathematical Treatment of Random Error

by Robert J. Brubaker

Introduction:

The initial unit of study for the physics students at Hempfield High School is a unit on measurement and error. This unit of study requires the student to read certain laboratory instruments and estimate the error. The student must then use the data collected in the laboratory to make calculations, graph the data, and report the results. All of these activities must be done using either explicit errors and/or significant figures.

Over the years I have observed that students will slavishly do the laboratory exercises associated with the unit, will listen to the lecture materials, learn the rules from the text, and then inevitably, upon the completion of the unit, revert back to writing down every figure on their calculators for every answer for the remainder of the year. It seems that by the time students reach their junior or senior years we teachers have so awed them with the complexity and correctness of our scientific laws that they are thoroughly convinced that scientific authority is the absolute. I and some of my cohorts have attempted to dissuade students by such threats as, "If the correct number of significant figures is not used in reporting answers, you will be penalized by a 10% reduction in your grade." Such techniques have had little success and students continue to report areas determined by mere ruler measurements to the 13th decimal place because that's the figure on the handy-dandy pocket calculator.

A few years ago I decided to use a different approach. I would teach some elementary theory of error analysis. If the students could grasp in some small way the methodology which a scientist must really use to obtain these wonderfully complex equations that seem able to do all things, then those students would begin to recognize the limits of science.

Another problem which has recently begun to appear in print is that of the makeup of the typical introductory physics course. Generally the offerings lean heavily on the side of the classical Newtonian physics, but are very skimpy in presenting modern physics. I feel personally that this is due to the limited amount of time we are given for science in the United States, but that is not something that is going to be remedied soon, therefore the individual teacher is responsible for attempting a balance. This unit is an attempt to take an area of study that has been done in a typical fashion and revise it to use and hopefully teach some modern concepts.

Lesson Objectives:

Upon completion of this unit on measurement and error, students should

1. have a better understanding of the limits of scientific laws.
2. be able to use explicit errors and/or significant figures to express and work with laboratory data.

3. be able to do calculations using explicit errors and/or significant figures.

4. be able to describe the operation of the Geiger-Muller counter.

5. state the makeup of the nucleus.

6. know the three types of radioactive emissions from the nucleus.

7. understand the meaning of instability of the nucleus and how it contributes to radioactivity.

8. be able to calculate the mean of a set of data.

9. be able to calculate the standard deviation of a set of data.

10. be able to construct a histogram or line graph of data.

11. be able to define and use the following concepts:

a. error	l. mean
b. mistake	j. standard deviation
c. random error	k. uncertainty
d. accuracy	l. error bar
e. precision	m. standard curve
f. explicit error	n. histogram
g. significant figure	o. relative or percentage error

LESSON I: Nuclear Theory and Radioactivity

The Nucleus

A. Radioactive decay - The spontaneous disintegration of a nucleus which results in an energy release in the form of emitted particles or rays from the nucleus of the atom.

1. Although decay itself is random, for a particular substance it is described by the decay constant.

2. The rate of decay is not affected by the environmental factors such as temperature, humidity, chemical reactions, etc. Each nucleus that emits a particle is independent of all other nuclei in a sample.

B. Structure and stability of the nucleus

1. The nucleus for our purposes will be thought of as consisting of neutrons and protons.

2. Z is the symbol used for the number of protons in the nucleus.

3. N is the symbol used for the number of neutrons in the nucleus.

4. A is the symbol used for the atomic mass number and $A = Z + N$

5. The term isotope is used to designate an atom that has the same number of protons as another atom, but a different number of neutrons.

6. Certain combinations of protons and neutrons in the nucleus seem to make the nucleus more stable than other combinations.

a. Neutron/proton ratio. If the ratio is too high (1.0 to 1.5 is the range from light to heavy nuclei), then the nucleus will be unstable and will decay.

b. Even - Odd Rule

proton #	neutron #	# of stable isotopes
even	even	157
even	odd	52
odd	even	50
odd	odd	5

c. Magic numbers. A high degree of stability is observed for nuclei with the number of protons or neutrons equal to 2, 8, 20, 28, 50, 82, 126. In general, whether Z, N, or A is equal to a magic number, and especially when Z and N are both magic numbers, the nucleus is very stable.

7. If the nucleus is unstable then it can decay by emitting an alpha particle, a beta particle, or a gamma ray.

a. Some nuclei can emit only one type of particle.

b. Other nuclei emit several types.

C. Definition of <u>random</u>. Tongue in cheek example:

1. How many of you students had a breakfast this morning?

2. Did that breakfast include a drink? Coffee, tea, milk, orange juice ?

3. All of you and all other students in this school who drank liquids are in an unstable state! Eventually some, maybe many, are going to need to use the lavatory facilities for an "emission".

4. The time at which you have to use the lavatory does not depend at all on any other student, nor is the time predictable for one student. We can not assign a particular time to each of you...Sally 8:30 A.M., Johnny 11:10 A.M. etc.

5. Perhaps if we did a study we could come up with how many per hour or some such thing, but each individual event is a random occurrence. (mathematicians would no doubt fault this as not a true random event, but for this purpose it's true enough).

6. This is also the case with unstable nuclei, except the numbers are much, much larger than numbers of students. For instance, you know that just one gram of hydrogen atoms would contain Avogadro's number of atoms or $6x10^{23}$ atoms.

7. If we had a mole of a radioactive isotope there is no way of saying when one of that vast number of atomic nuclei would undergo a radioactive emission, but we can do a study of all of them over a period of time and perhaps arrive at some rate of decay that is constant.

8. We will then do some activities that will allow us to determine mathematically how random events can be treated so that we can say that we at least know something about the phenomenon.

9. Scientist say that when they can measure something quantitatively, then they know something about that thing.

LESSON II: Laboratory Exercise Using a G-M Counter

Modification of Experiment IV, Radiation Counting Statistics. Nuclear Issues and Technology Laboratory Experiments Notebook, Dr. William Jester and others, 1990.

Due to a lack of sufficient numbers of counters, the collection of the data is done as a group exercise. On the front laboratory table I set up our G-M counter and a video camera attached to several computer monitors so that everyone has a good view of the experiment. I take forty counts of 30 seconds each, using a sealed beta or gamma source. Students record data on laboratory sheets.

Theory:

Radioactive decay is a random event. The decay of one atom is independent of all the other atoms.

The number of atoms undergoing decay in one time interval or another will differ. How many will decay in a given interval of time can be approximated by taking a large number of readings and then getting an average number per time interval.

The more readings that are taken, the more faith we can put in the value that we get.

Procedure:

1. Sort your data by arranging it from the smallest value to the largest value.

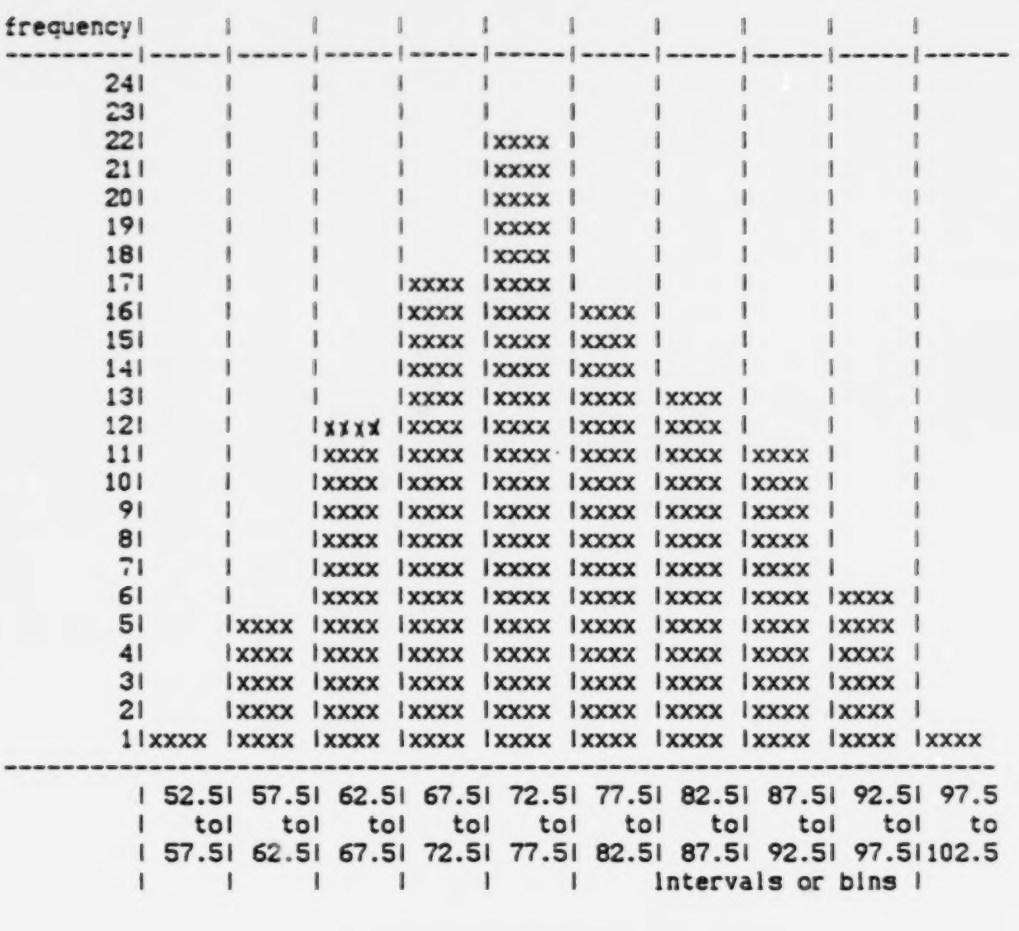
2. Subtract the smallest value from the largest value and divide this by ten.

3. Round this off to the nearest whole number, preferably an odd number. If even, add one.

4. Use the smallest value of your data as the mid point of an interval equal to the value in number three.

5. Set up intervals equal to the value in number three until the largest data value falls into one of the intervals.

Sample Histogram



data:

55 58 63,63 68,68 73,73 78,78 83,83 88,88 93,94 98
58 63,63 68,68 73,73 78,78 83,84 88,88 94,96
60 64,64 68,69 74,74 78,78 84,84 88,89 97,97
60 66,66 69,69 75,75 78,78 84,86 89,90
62 66,67 69,71 75,75 79,79 86,87 90,91
67,67 71,71 76,76 79,80 87,87 91
71,71 76,77 80,81 87
71,72 77,77 81,82
72 77,77
77,77
77,77

average = 76.9
std. dev.= 9.7
number of measurements = 104

6. Now count the data points that fall into each of your intervals which we will now call "bins". (See the example to discover how this is done).

7. You will now use this information to plot a special kind of graph called a histogram. Again see the example for help.

8. The count intervals or bins will be along the X-axis and the frequency will be along the Y-axis.

9. Place a point at the middle of the top of each bin on the histogram and connect these points with the smoothest line that you can.

10. Finally, add all your original counts together and divide by 40. This is the average number of counts. Mark this on your graph line.

LESSON III: Review of Laboratory Data and Demonstration of Statistics Used

Shape of the histogram

A. Notice the shape of the curve that you have constructed by connecting the mid points of the tops of the bins.

1. If we had taken more measurements, we would begin to see a very definite shape to this curve.

2. This curve is called the limiting distribution and would look like the curve on the overhead. (Show a normal curve).

B. The average or mean value and its meaning.

1. Notice that the measurements seem to all cluster around the average value. This is true even for the curves that we have made.

a. These values then seem to be the ones that we would get most often.

b. What this tells us then is that the mean is the most likely measurement that we will get no matter how many times we take a particular measurement in the same way of the same thing.

c. We then can make the statement that "the mean of many measurements is the most likely true value".

2. Here let me digress for a moment and discuss the true value of a measurement. This is a difficult question to answer, and in truth there is no satisfactory, simple answer. Since it is obvious that no process of measuring can exactly determine the one true value of a measurement, it is not clear that the true value of a measurement actually exists. We are forced to accept a concept similar to the mathematician's "point with no size" or "line with no width" --that is, we think of the true value as a useful idealization.

3. This idea that the measuring process does not ever allow us to say that a particular measurement is the true measurement is what we call the uncertainty of the measuring process. The uncertainty is also called the random error.

a. Error as used by the scientist has a different connotation than the term used in its everyday usage.

b. It does not mean "mistake" or "blunder", but rather the uncertainty that we have about a particular value.

4. And now back to the mean. From our graph we now can see that the most likely value to accept as the so called "true value" is the mean.

C. There are other values on our graph. How do they fit into the scheme? (Do this as a problem on the overhead projector.)

1. The values to the left and the right of the mean value occur less often the farther from the mean that we move along the curve.

2. We can analyze this curve and determine how likely it is that any of these values will show up in a series of measurements. Also we can use our analysis to tell whether our method of measurement is working.

3. We would like to be able to look at our measurements and determine what is the average error in our measurements. If you try this what you find for a large number of measurements is that the sum of all the differences between the average and the individual measurements always gives zero for an answer.

4. We get around this by squaring all the values, then the negatives become positive.

5. Then we divide by the number of measurements and take the square root of the result. This is called the standard deviation of the mean.

6. If we were to count the number of our measurements one standard deviation to the left on our curve and one standard deviation to the right, we would find that 70% of the measurements fit between these two values.

7. We often use this to express the "error" in our measurements explicitly.

a. Suppose that the standard deviation (S.D.) = 5.5

b. We might express our measurement as: 76 +/- 5.5

c. This is the confidence level of our measurement.

LESSON IV: Group Laboratory: Measuring the Length and Diameter of a Cylinder

Uncertainty Theory

A. When a value is not known exactly, the amount of uncertainty is called the error. This has connotations in uncertainty analysis because of the common usage of the term error which is usually meant to signify some mistake on the part of the measurer.

1. But in science the term "error" does not designate any kind of mistake or sloppiness. It measures the uncertainty that is present in any measurement.

2. No measurement is "true" in the sense that we can ever be sure that another measurement made in the same way would give the same value.

B. Uncertainty and the device that is used to measure a quantity.

1. When we read the scale on a device we are always making judgments. We can express these judgments in several ways:

a. If I write down a number to express a measurement such as: 36mm

a person trained in science would see this as implying that the measurement was:

$$35.5\text{mm} < L < 36.5\text{mm}$$

b. If I had written it as: 36.3mm

then it would be perceived as: $36.25\text{mm} < L < 36.35\text{mm}$

2. Best estimate +/- uncertainty. (Absolute error).

a. If I use a device to make a measurement, I can see on the device a closest measurement. Then I can estimate a figure and determine how close to that estimate I think I can get using that particular device.

b. In this lab we will take many measurements and find the mean and standard deviation. Then we will use these values to assign our error.

Procedure:

A. Pass around the room a cylinder and an ordinary centimeter rule. Each student will measure the length of the cylinder and the diameter of the cylinder.

1. The length will be easy and should have a small error.

2. Measuring the diameter will not be as easy since it is not easy to determine the center of the circular end. This should give a larger error.

B. Measure these values and record them. Do not tell the next person your answers so that you do not skew the results. (define skew). When everyone has made the measurements, collect the results and post them all so that everyone will have all the results.

1. Find the mean of the length.

2. Determine the mean of the diameter.

3. Determine the standard deviations of each of the measurements.

4. Express each measurement in terms of its explicit error. Show all calculations on your laboratory sheets.

LESSON V: Working with Explicit Error and Significant Figures

Definition of absolute error

A. The absolute error is defined as the difference between the deviation from the mean and the mean. Sometimes there is a measured value that is the result of scientists making the same measurements over and over by better and better methods and this value then is accepted as a standard value, for instance, g=9.801 m/s/s

$$O - A = E_a$$

where O is your observed value, A is the accepted standard or mean, and E_a is the absolute error.

B. Example of uses of absolute error:

We measure the three sides of a triangle with a ruler that allows us to state that--

$$S_1 = 23.43 \text{ +/- } .02\text{cm}$$

$$S_2 = 53.46 \text{ +/- } .02\text{cm}$$

$$S_3 = 3.25 \text{ +/- } .02\text{cm}$$

We wish to determine the perimeter and its error so we add the three measurements:

$$23.43\text{cm} + 53.46\text{cm} + 3.25\text{cm} = 80.14\text{cm}$$

Then we subtract the amount of error (.02 cm) from each and get the minimum that it could be--

$$23.41\text{cm} + 53.44\text{cm} + 3.23\text{cm} = 80.08\text{cm}$$

Then we add our error to each and get the maximum that it could be--

$$23.45\text{cm} + 53.48\text{cm} + 3.27\text{cm} = 80.20\text{cm}$$

Note that the minimum value of the perimeter is .06 below the added measurements and the maximum is .06 above the added measurements; in other words, the absolute error adds when we add.

The rule then is: **When adding or subtracting measurements, the absolute errors add.**

C. Percentage error or relative error:

1. If I express a number explicitly such as: 21.53 +/- .02

where .02 is the absolute error, then I can take this error and express it as a percent of the best estimate

$$.02/21.53 \times 100\% = 0.093\% = 0.1\%$$

2. My number then can be expressed as:

$$21.53 \pm 0.10\%$$

3. This is called the relative or percent error and is defined as:

$$(E_a/A)100\% = E_r$$

4. **When you multiply or divide a set of values, the per cent errors add.**

D. Use the ideas that we have just discussed to determine the volume of the cylinder that you measured in the lab yesterday. Record this on your laboratory sheet. All laboratory materials will be collected for a grade tomorrow.

Significant figures

A. There is another method for expressing errors that is not as versatile nor as good as the absolute error or the percentage error, but is usually sufficient for most of our work. This method is to use the correct number of significant figures to express an answer that implies the explicit error.

2. Significant Figures - A first order approximation to error analysis. The number of significant figures in a value is an approximation showing the error limits to which a value is known.

3. A number expressed as 3 signifies by convention that the value is known to be between 2.5 and 3.5. One significant figure:

$$2.5 < N < 3.5$$

B. If we express a value as 3.0 it signifies that: Two significant figures:

$$2.95 < N < 3.05$$

C. Significant figures are loosely related to the idea of relative error:

1. For example consider the two numbers: 510 and 0.51

Both contain two significant figures. These could be written explicitly as

510 +/- 5 or 510 +/- 1%

0.51 +/-.005 or 0.51 +/- 1%

2. Looking at a second example we see: 110 +/- 5 or 110 +/- 5%

If we compare this with the first example in #1, we see that as the number gets smaller, even though it still has two sig. figs. the percent error is larger.

3. Looking at still another number: 910 +/- 5 or 910 +/- 0.5%

Here we see that with two significant figures as the number gets larger, the per cent error gets smaller.

4. Roughly then we can get a connection between the number of significant figures. and the percent error as shown below:

# of Sig. Figs		relative error range
1	--------	5 & 50%
2	--------	0.5 & 5%
3	--------	0.05 & 0.5%

5. Why do we concern ourselves with this approximate relationship? Because with first order approximations we frequently have problems trying to determine the number of significant figures to assign to a calculated value or we assign the number according to a set of rules and actually change the accuracy of our answer due to the crudeness of the significant figure approximation.

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Lessons on Radioactivity Using the Learning Cycle Format

by Michael Keely

This project is a series of lessons on radiation constructed on the three-phase learning cycle format. The learning cycle is founded on Jean Piaget's theory of cognitive development. The first phase, **exploration**, provides a physical experience that creates a need for further understanding within the student. The second phase, **concept introduction**, uses lab activities, textbook readings, computer activities, group instruction, and audio-visuals to develop and explain the concepts explored in phase one. During the third phase, **concept application**, students must use what they have learned in the first two phases to solve a new situation or problem.

The set of lessons is for a group of eighth grade students of varied academic abilities. Lessons are designed for learning/lab groups of up to six students.

PHASE I - EXPLORATION

Several days before actually introducing these lessons, place a pitchblende sample on a package of instant developing film. Allow this to remain in view of the students until the lessons on radioactivity start.

ACTIVITY 1

A. Materials (for each student team)

1. An electroscope, rubber rod, and fur piece

2. A pitchblende sample

3. Tongs for holding the pitchblende

B. Procedure

1. Charge the electroscope by rubbing the hard rubber rod on a piece of fur; then rub the rod on the metal bulb of the electroscope.

2. Students should answer the following questions:

a. What do you observe?

b. Why did you observe this?

* Students should have already been introduced to the idea of static electrical charges and that like charges repel.

3. After using tongs to bring the pitchblende near the electroscope answer these questions:

a. What happened to the leaves of the electroscope?

b. What could have caused this?

4. Repeat steps 1-3 several times.

ACTIVITY 2

A. Materials (for each team)

1. Plastic cloud chamber (See Appendix B, Equipment Sources #1 and Information Sources #5)

2. Alcohol

3. Dish

4. Flashlight

5. Dry ice (handled only by the teacher)

6. An old Coleman lantern mantle, rolled up and tied, or small piece of uranium ore

B. Procedure

1. Saturate the felt band on the inside of the cloud chamber with alcohol.

2. Place the lantern mantle or rock in the cloud chamber and place the lid on the chamber.

3. Place the cloud chamber on top of the dry ice in the dish.

4. Turn off the classroom lights and direct the flashlight beam through the side of the cloud chamber.

5. Lightly placing your hand on top of the chamber provides a heat source.

6. Ask, "What do you observe in the cloud chamber?"

7. Ask, "What could be causing this?"

ACTIVITY 3 The teacher should place the film that has been exposed to the pitchblende in an instant developing camera. After covering the camera lens so no light can enter, snap a picture for each lab group.

A. Materials - a photograph from the package that has been exposed to the pitchblende.

B. Procedure - observe photograph and answer the following questions

1. What do you observe?

2. What could have caused this?

PHASE II - CONCEPT INTRODUCTION

In phase two, concept development, the teacher uses a variety of methods and materials to enable the student to develop the needed concepts. Prior to these lessons, the students should have developed concepts about atomic structure (molecules, atoms, electrons, protons, neutrons, atomic number, atomic mass, mass number, and isotopes).

ACTIVITY 1 The idea that ionizing radiation comes in several forms and that these forms have their own physical properties needs to be presented several different ways.

A. Materials

1. A large (4 ft.) beach ball represents an alpha particle.

2. A small (1 in.) "Nerf" ball can be compared to a beta particle.

3. A flashlight beam can be used to show gamma ray properties.

B. Procedure

1. In a gym or other open area, students can throw the beach ball (alpha), shoot the "Nerf" ball from a Blast-o-matic (beta), and shine the flashlight (gamma).

2. Ask the following questions.

a. Which radiations are particles?

b. Which are rays?

c. What is the difference between a ray and a particle?

d. Which radiation goes the greatest distance?

e. Which radiation goes the shortest distance?

ACTIVITY 2 This activity will distinguish among the three types of radiation and determine what effect distance from the source has on radiation.

A. Materials

1. Geiger Muller scalar (See Appendix B, Equipment Sources #4 and #5)

2. Tweezers

3. Sealed alpha, beta, and gamma sources

4. Copy per student of Investigation 10, IIS (Dolmatz and Wong. Physical Science Idea 3: Energy. Prentice-Hall, Inc. NJ 1976.)

B. Procedure

1. Students should warm up their scalars and take three one-minute counts with no radiation source near the G.M. tube. (The concept of background radiation should

be introduced here. It should be accompanied by an explanation of the effect of random decay, soil properties, geographic location, and altitude.)

2. For the purpose of this experiment, the average background should be subtracted from each later reading in the experiment. Negative outcomes should be recorded as "0".

3. Students should next perform Investigation 10, Part A, of Idea 3: Energy.

4. Students should repeat the experiment three times, making appropriate data tables and graphs for an alpha, a beta, and a gamma source.

5. Have students compare and contrast the effects of distance on the three different types of radiation.

ACTIVITY 3

A. Materials

1. Four-foot beach ball

2. "Nerf" ball and gun

3. Flashlight

B. Procedure

1. Return to gym or large open area.

2. Students will play the part of atoms in a solid. They will be arranged in orderly rows and not allowed to move, only sway back and forth.

3. The teacher then throws the beach ball toward the students, thus representing the release of an alpha particle toward the solid.

4. Repeat several times, having students note the average distance the ball penetrated the formation.

5. A beta particle is directed toward the solid (a "Nerf" ball fired from a "Blast-A-Ball").

6. Students should note average penetration and if any particles penetrated the whole formation.

7. The gamma ray (flashlight) is directed toward the solid.

8. Students should again note average penetration and if the ray penetrated the whole formation.

9. Students should answer the following questions:

a. Which type of radiation is most penetrating and why?

b. Which type of radiation is least penetrating and why?

10. Students should complete Investigation 10, Part B, of Idea 3: Energy using only the beta source.

ACTIVITY 4 This experiment is used to show, in a simple fashion, the effect of exposure time on radiation dose.

A. Materials

1. Geiger Muller scalar

2. Sealed beta source (Appendix B, Equipment Sources #2)

B. Procedure

1. Place the sealed beta source on the second shelf of the G.M. scalar.

2. Take counts for 1, 2, 3, 4, and 5-minute segments.

3. Complete the data table.

4. Make a line graph labeled "Counts Per Minute vs. Time."

5. Predict the amount of radiation if the exposure continued for ten minutes.

6. What is the relationship between the time of exposure and the total amount of exposure?

Exposure Time	Total Counts
1 minute	_____
2 minutes	_____
3 minutes	_____
4 minutes	_____
5 minutes	_____

7. Now is an appropriate time for the use of audiovisual materials. These might include:

a. Britannica, "Learning About Nuclear Energy".

b. Centron, "Matter Into Energy".

c. Coronet, "Introducing Atoms and Nuclear Energy."

Readings about nuclear energy and radiation can be made at this time using texts available to the teacher. A concept review should be conducted by the teacher at the end of this phase.

PHASE III - APPLICATION

Activity This activity enables students to use what they have learned to solve a new problem.

A. Materials - Map of a portion of a campus showing the location of a building as a storage area and laboratory for radioactive materials. (See example below)

B. Procedure

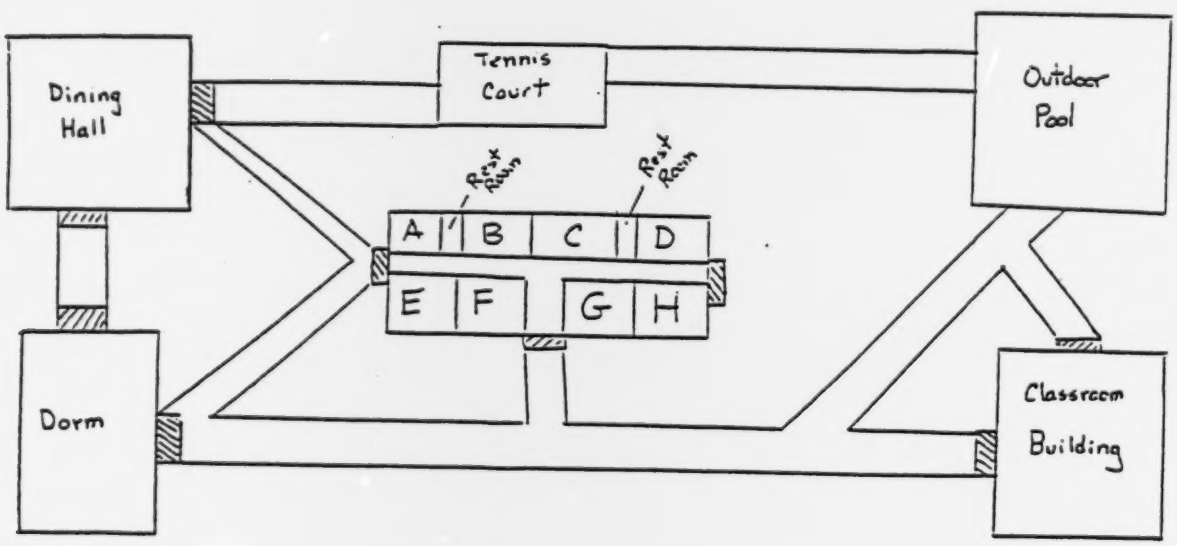
1. Student groups decide on what floor and in what area of the building this lab/storage is to be located.

2. Student groups write a report in which they reveal the location of the lab/storage area, describe any modifications to the room, and offer support for their decision. This support should show that students accept the concepts that:

a. Matter protects us from radiation.

b. Distance offers protection from radiation.

c. The less time you are in proximity to radiation, the less is your exposure.



Davison Hall, in center, is a three story brick building.

References

Dolmatz and Wong. "Investigation 10 IIS " Physical Science Idea 3: Energy. Prentice-Hall, Inc. NJ 1976.

Beanium Lab

by Marie Reluga

Background and Pre-lab Questions: This lab may be completed in approximately 50 minutes and is designed for students in the academic, college prep or honors levels. Students may work individually or in groups of two. The following pre-lab questions and problems should be done by students and discussed prior to the lab:

1. What is the basic atomic difference between isotopes of the same element?

2. If there are 100 navy beans, 27 pinto beans and 173 black-eye peas in a container, what is the per cent composition of the contents of the container?

3. If your chemistry grade is broken down so that 60% is based on tests, 25% on labs, and 15% on homework, and your scores are: exams - 85, labs - 75, and homework - 96, what would be your weighted average score?

Objectives: to appreciate isotopic variations within an element
to understand how the average atomic mass is determined
to understand that although atoms of the same element have different isotopic masses their average atomic mass is representative of all isotopes of the element

Equipment: balance, 500 beans in a Zip-lock bag (mixture of pinto, navy, and kidney beans. **(Each type of bean represents a different isotope of the element "beanium")**

Procedure: 1. Sort the atoms (beans) by type. Record total number of atoms in your sample. Then record the number of each type of atom (bean) in the data table.

2. Mass each isotope of beanium and record.

Calculations: 1. Calculate the mass of a single atom of each isotope.

2. Determine the % abundance of each isotope.

3. Determine the atomic weight or "weighted average mass" for beanium based on per cent abundance of each isotope and their respective masses.

Post-lab Questions:

1. What is the weighted average atomic mass of beanium?

2. A student obtained the following data when measuring her beanium sample:

type of bean	# of beans	mass of sample
pinto	152	59.431 g
navy	191	51.660 g
kidney	292	62.581 g

Calculate the following:

a. the % composition of each bean

b. mass of each isotope

c. the atomic mass of beanium

3. Define isotope. Explain the difference between $^{20}_{10}Ne$, $^{19}_{10}Ne$ and $^{22}_{10}Ne$.

4. The following are natural isotopic abundances of magnesium. Calculate the average atomic mass of magnesium.

Mg - 24	78.99%
Mg - 25	10.00%
Mg - 26	11.01%

References

Miller, Greg. "It's Beanium" J. Chem. Ed. June 1981.

An Activity for Illustrating the Concepts of Atomic Mass and Mass Number for Physical Science Students

by Hans Gougar

Introduction:

In my experience with 9th grade Physical Science students, many of them have had a large degree of difficulty distinguishing between the concepts of the *atomic mass* of an element and the *mass number* of an isotope. Most can grasp the idea of atomic number and how it relates to the structure of the atom, and few actually have difficulty distinguishing between atomic number and atomic mass. However, the confusion is apparent when I begin to discuss atomic mass and mass number at the same time. The activity we performed at the beginning of the course involving the mass of pennies helped me to devise a similar activity using paper clips which may help alleviate this problem.

Strategy:

The lesson begins with a discussion (review) of the three major concepts. These activities are simplified in that they assume the mass of both the proton and the neutron to be 1 atomic mass unit (u). Also, the mass defect due to the binding energy of the atom is not discussed. Therefore, one may wish to point out that this is not a perfect analogy or explanation for atomic mass, but that it does help in seeing the difference between the concepts.

Major Concepts to be Discussed:

Atomic Number - the total number of protons in one atom of an element. This is always an integer since protons cannot be broken into parts. Each element has a unique atomic number and can be identified by this number.

Mass Number- the total number of nucleons (protons and neutrons) in an atom. This is also a whole number. Different atoms of the same element will have different mass numbers if they have different numbers of neutrons. These atoms are called isotopes.

Atomic Mass - the *average* mass of all the atoms in a sample of a single element. This is a property of an element, not of a single atom. The atomic mass is rarely a whole number. However, since it is an average mass, quite often (but not always) it has a value close to the mass number of the most abundant isotope.

Example: Most carbon atoms (about 99%) have 6 protons and 6 neutrons. This isotope of carbon is called carbon-12 because the mass number is 12. Some carbon atoms, however, have 6 protons and 7 neutrons. This isotope is called, naturally, carbon-13. There are many more carbon-12 atoms than carbon-13 atoms so the *average mass* of a carbon atom is closer to 12 than to 13. The atomic mass of carbon is actually 12.01 atomic mass units (u). The calculation is actually a mixture problem, like those one often encounters in algebra classes.

$$(100\%)\ (\text{atomic mass}) = (98.9\%)\ (12) + (1.1\%)\ (13)$$

$$100\ (\text{atomic mass}) = 1186.8 + 14.3$$

$$\text{atomic mass} = 12.01\text{u}$$

Activity I - Finding the Approximate Atomic Mass of Chlorine

(This first part can be performed individually or in pairs. It requires no materials)

Chlorine has two stable isotopes. One has 35 nucleons (C1-35) and the other has 37 nucleons (Cl-37). About 75% of all chlorine atoms are Cl-35. The remaining atoms are Cl-37. Suppose you had a sample containing 20 atoms. Determine the following information for the sample.

Approx. no. of Cl-35 atoms - _____ x 35 = _____ (number of Cl-35 nucleons)

Approx. no. of Cl-37 atoms - _____ x 37 = _____ (number of Cl-37 nucleons

Total number of atoms 20 _____ = total nucleons

Divide the total number of nucleons by 20 to find the average number of nucleons per chlorine atom. Round this number to 1 digit past the decimal.

If the mass of both the proton and neutron is 1u, what is the atomic mass of chlorine? _____

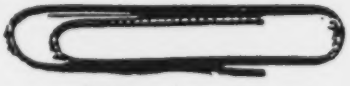
What is the most abundant isotope of chlorine, C1-35 or C1-37? _____

Activity II - Measuring 'Atomic' Mass

(Before the class begins, prepare samples of 'paperclipium' by mixing different sizes of paper clips such as the ones shown. Try to count the same number of each size into each sample so that the relative abundance found by each group is the same. For example, each sample may contain 3 small paper clips, 37 medium paper clips, and 15 large paper clips)

small

medium



large

Take some 'atoms' of the element paperclipium from the container. Notice that some of the atoms are different sizes. These different atoms represent different isotopes of an element. Perform the following measurements to find the atomic mass of the paperclipium. Use the table that follows to record the data.

Questions:

1) How many atoms are in your sample? Record.
2) How many isotopes of paperclipium are in your sample? How many atoms of each isotope? Separate out one atom of each isotope.
3) Measure the mass of one atom of each isotope (mass number) and record.
4) Measure the mass of the entire sample.
5) Divide the mass of the entire sample by the total number of atoms to find the average mass of one atom of paperclipium. This is the *atomic mass* of paperclipium.
6) Which isotope has the mass number which is closest to the atomic mass of paperclipium?
7) Which isotope is the most abundant? (see part 1)
8) Are the answers to parts 6 and 7 the same?

Data:

1) Total number of atoms

2) Number of isotopes _____ Label each isotope with a name that identifies it. (ex. big, small, black, etc.)

3) Number of atoms of each isotope _____ _____ _____

4) Mass of 1 atom of each isotope(g) _____ _____ _____

5) Total mass of sample _____

6) Atomic Mass of paperclipium (average mass of all atoms)_____

7) Isotope with mass closest to atomic mass (compare Q.4 with Q. 6)_____

8) Most abundant isotope _____ (see Q. 3)

9) Is your answer to q.6 the same as that of q.7?_____Does this agree with what we learned about atomic mass?_____

Other Questions and Activities

1. Look on the Chart of the Nuclides (Appendix B, Information Sources #1.) and determine which element has the greatest number of stable isotopes (shown in gray).

2. What is the difference between water made with ^{1}H atoms and water made with ^{2}H (deuterium) atoms? Do you think they will react with other compounds in the same way? Explain.

3. In this lab, we separated paper clips by hand. However, to separate isotopes of real elements requires some sophisticated techniques and equipment. In the library investigate the various isotope separation methods and write a paragraph on one of these methods.

Extra - Some elements, like gallium, have an atomic mass which does not round off to the mass number of the most abundant isotope. Look on a Chart of the Nuclides to find the atomic mass of gallium and its most abundant isotope. Explain why these numbers are different.

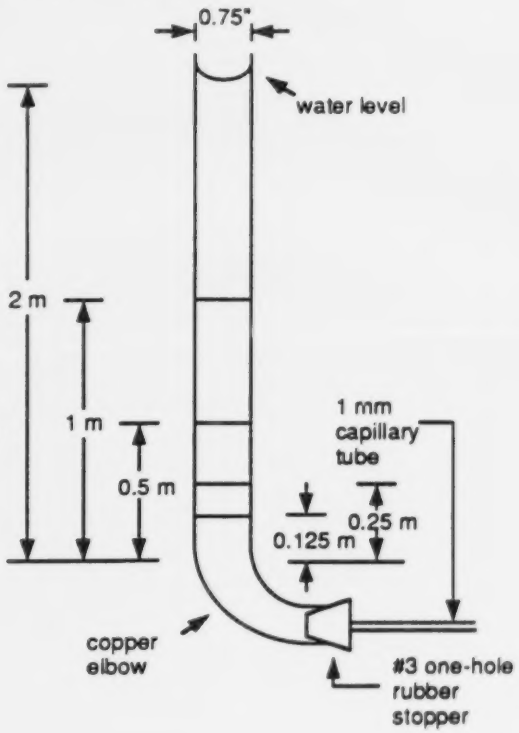
Half-Life Demonstration

by Joseph Sean Moore

This simple demonstration avoids the counting of myriad small pieces (sugar cubes, M&Ms, pennies, etc.) to illustrate the basic concept of a half-life, i.e. the amount of time needed for one half of any sample to decay. The apparatus is easily constructed, the demonstration requires very little time, and the results are usually fairly reproducible.

Materials:

Transparent plastic pipe (0.75 " outside diameter and slightly longer than 2 meters)
Ring stand with clamps to hold pipe vertically
0.75 " copper 90° elbow
#3 one-hole rubber stopper
12 inch piece of 1 mm inside diameter capillary tubing to fit in rubber stopper
Sink or bucket for water
Large stop-clock, preferably digital
Food coloring (optional)



Apparatus Set-up:

1. Mark the transparent plastic pipe at the following lengths from one end: 2m, 1m, 0.5m, 0.25m, and 0.125m.

2. Stand pipe upright with 2m mark near the top. Clamp pipe to ring stand and position close to sink (or bucket on floor.)

3. Insert capillary tubing into rubber stopper. Insert rubber stopper into copper elbow. Place copper elbow beneath plastic pipe and insert pipe snugly in to copper elbow.

4. Set clock to zero and position it close to the apparatus.

Procedure:

1. Fill transparent pipe, elbow and capillary tube with water (colored or plain) until water level is at very top of pipe. As water level falls, start clock at the instant the water level reaches the 2m mark. When the water level reaches the 1m mark record the time. When water level falls to the 0.5m mark and then the 0.25m and 0.125m marks, record the times also.

2. Compare the elapsed times for each of the four runs: 2m to 1m, 1m to 0.5m, 0.5m to 0.25m and 0.25m to 0.125m.

23

3. Repeat entire experiment (step one) if desired.

Questions:

1. What is the average value of the elapsed time of the four runs?

2. How is this value like the half-life of a radioactive nuclide?

3. In nature nothing has been found to alter the half-life of a specific radioactive nuclide. What alterations could we make to our demonstration apparatus that would probably change the apparent half-life?

References

Dr. Richard Berg, Department of Physics, University of Maryland, College Park, MD.

Sources of materials:

0.75 " outside diameter transparent plastic pipe is available from :

Gar-Ron Plastics Corp., Baltimore, MD, (800) 492-4695,
FAX: (410) 483-1493

or

Harrisburg, PA, (800) 442-6839, FAX: (717) 558-2199

0.75 " copper elbow is available at most local hardware stores.

Lab Illustrating Random Disintegration

by Sam Smith

Introduction and Purpose:

In nature an interesting phenomenon is that there is an observed half life for each isotope of a radioisotope. This means that, for a given length of time, half of a certain quantity of atoms will disintegrate. Yet there is no way of knowing which atom may disintegrate at any specific time. This lab is to illustrate the randomness of this disintegration.

Materials:

Microwave oven which has a light to observe item being cooked
Popcorn - 25 kernels (microwave packaged popcorn works best)
Paper towel
Sheet to record order of popping
Felt marker (wide)
Clock or watch with second hand

Procedure:

1. On a sheet of notebook paper draw a square 5 inches on a side using a bold felt marker. Draw lines 1 inch apart inside the square both ways so you end with a grid with 25 squares. Then draw a similar grid on a paper towel.

2. Place the towel on the glass tray in a microwave oven. Then place one kernel of corn in the center of each square.

3. Set the microwave oven for 15 minutes. (This time may vary depending on the popcorn and/or the power of the oven.)

4. Turn on the oven. Observe and record the time and order that the popcorn pops on your grid. Record the time it took for the first kernel to pop and approximately how many seconds to each successive popping. Record how many kernels were left after 15 minutes. If less than half the popcorn popped, repeat the heating time another 5 minutes.

5. Munch on the popcorn as you complete the questions.

Questions:

1. Was there any logical sequence to the order of the popping of the popcorn?

2. Explain any sequence to the order of the popping you observed.

3. After the corn started popping, was there any order to the amount of time between successive poppings? _____ Explain.

4. On the grid below record the order and time elapsed between poppings.

Order and Time Elapsed Between Poppings

Order____ Time_____	Order____ Time_____	Order____ Time_____	Order____ Time_____	Order____ Time_____
Order____ Time_____	Order____ Time_____	Order____ Time_____	Order____ Time_____	Order____ Time_____
Order____ Time_____	Order____ Time_____	Order____ Time_____	Order____ Time_____	Order____ Time_____
Order____ Time_____	Order____ Time_____	Order____ Time_____	Order____ Time_____	Order____ Time_____
Order____ Time_____	Order____ Time_____	Order____ Time_____	Order____ Time_____	Order____ Time_____

5. What was the popcorn "half life?" (The "half life" is the time from the first pop to when half of the kernels were popped)

6. Are there any other events in nature which seem to have a random order? _____ If so, name and describe the events.

The Ionization Potential of Argon

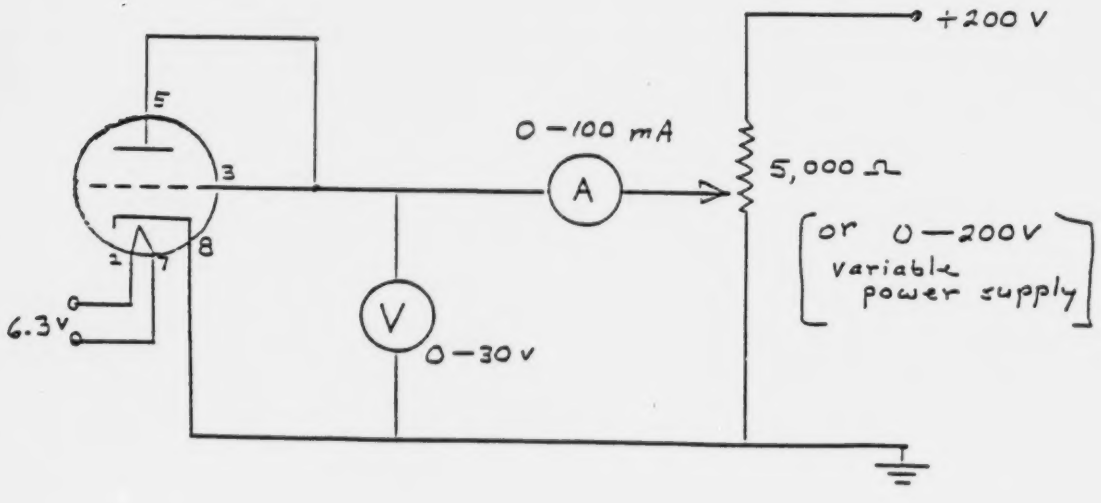
by Philipp G. Schmelzle

Introduction: The ionization potential of an element is defined as the energy (in electron volts) required to remove the most loosely bound electron from the normal atom. The existence of a discrete ionization potential for each element confirms the existence of stationary states as postulated by Bohr and mathematically derived by Schroedinger. The ionization potential of argon can be found by using an argon filled radio tube (thyrotron 884).

A comparison of ionization potentials of elements shows that alkali metals (Li, Na, K, Rb, Cs and Fr) have low values, about 5 volts, while the inert gases (He, Ne, Ar, Kr, Xe and Rn) have the highest values. The inert gases represent those atoms in which all the electron subshells are complete. The addition of one more proton to the nucleus and the addition of one more electron to the outer structure of an inert gas to make the next atom, an alkali metal, requires that the electron go into a new subshell, an outer orbit. Such an electron, located on the average farther away from the nucleus, requires less energy to remove it from the atom. As protons are added to the nucleus and electrons are added in this subshell, the binding of the electrons in the atom grows stronger.

Apparatus and Procedure: Assemble the circuit as shown in the schematic diagram (note the tube's pin numbers). The 884 radio tube is a low pressure, gas filled (argon), triode. For this experiment the grid and plate will be connected together, so the tube will act as a diode. A tube manual provides the following information about the 884 tube:

filament or heater: 6.3 volts, 0.6 amp
peak anode voltage: 300 volts
maximum anode current: 300 milliamp



To operate the circuit, vary the voltage between the cathode and the grid/plate while monitoring the current with the ammeter. When the tube is operating properly, the grid is positive with respect to the cathode and electrons thermally emitted from the cathode are accelerated toward the grid. Along the way the accelerated electrons may strike argon atoms with which the tube is filled at low pressure. At low voltages the collisions are elastic, and the argon atoms are not altered. At any potential, V, the electrons have a kinetic energy

$$(mv^2)/2 = q_e V$$

which the electrons may transfer to the argon atoms by collision.

As the grid/plate is made increasingly positive the electrons finally acquire enough energy to ionize argon atoms with which they collide. The cathode to grid/plate potential difference at which this occurs is the ionization potential, V_i. Therefore, $V_i q_e$ is the minimum energy sufficient to ionize the argon atoms, that is, to remove an electron from the argon atom.

Experimentally we recognize this voltage by the rapid increase in the ammeter reading and by the sudden glow of light that appears in the center of the tube at the same moment. The rapid increase in ammeter reading is caused by the increase in number of electrons between the cathode and grid/plate (anode). Some of the accelerated electrons bumping their way from cathode to anode acquire enough energy to knock electrons off the argon atoms. The electrons liberated from the argon atoms contribute to the anode current. The sudden onset of light in the argon filled tube and the sharp increase in current from cathode to grid/plate occur simultaneously as the critical potential, V_i, is exceeded. This is evidence that the argon gas is in a different condition.

The ionization potential for argon is 15.7 volts. At this point the kinetic energy of the ionizing electrons is

$$(mv^2)/2 = V_i q_e = (15.7 \text{ joule/coulomb})(1.6 \times 10^{-19} \text{ coulomb/electron})$$

$$= 2.51 \times 10^{-18} \text{ joule/electron}$$

The implication is that electrons are bound to argon atoms by a definite binding energy which is being measured by the energy needed to remove electrons altogether from argon atoms.

Analysis:

1. Plot a graph of voltage (between cathode and grid/plate) versus current.

2. Does the graph show an abrupt change in slope? Determine the voltage where the slope changed (where the current suddenly increased).

3. Determine the percent difference between the voltage determined in question #2 and the accepted value for the ionization potential of argon.

4. What is the law of Child-Langmuir?

5. How does the law of Child-Langmuir relate to this experiment?

6. How does this experiment differ from the Franck-Hertz experiments?

References

American Radio Relay League. The Radio Amateur's Handbook. 1969. Ch 25 and p. V24.

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Richards, James A., Francis W. Sears, M. Russell Wehr, and Mark W. Zemansky. Modern College Physics. Reading: Addison-Wesley Publishing Co., Inc. 1964. pp. 747-753.

Semat, Henry Introduction to Atomic and Nuclear Physics. New York: Holt, Rinehart and Winston. 1966. pp. 248-252.

Serway, Raymond A., and Jerry S. Faughn. College Physics. New York: Saunders College Publishing, Harcourt Brace Jovanovich, Publisher. 1992. pp. 950-954.

White, Harvey. Modern College Physics. Princeton: D. Van Nostrand Company, Inc. 1962. pp. 564-566.

Researching Nuclear Scientists

by Sandra J. Parente

This purpose of this project is to have the student see the scientists who have contributed some of the greatest advances in nuclear science as "real people", not just as a name and facts to be learned. Through research into the person's life and work and placement of information obtained into forms that are familiar to the student, it is hoped that the scientist will "come to life".

From a list of scientists the student selects one name to be researched. Research is done in the normal manner but with data geared to the completion of the following items:

1. Birth certificate

2. School record

3. Letter written home to parents during college OR letter written to colleague during research of major accomplishment, i.e. Nobel Prize work, etc.

4. Resume

5. Acceptance speech for Nobel Prize (or other award)

6. Death notice as written in local newspaper

Other items that could be included are a 2-3 minute audio tape in which the student plays the part of the scientist OR a brief video tape depicting a particular aspect of the life of the scientist.

List of Nuclear Scientists For Study

Henri Becquerel

Neils Bohr

Max Born

James C. Chadwick

Arthur H. Compton

Marie Curie

Pierre Curie

John Dalton

Albert Einstein

Enrico Fermi

Otto Hahn

Irene Joliot-Curie

Lise Meitner

Robert Millikan

J. Robert Oppenheimer

Wolfgang Pauli

Max Planck

Wilhelm Roentgen

Ernest Rutherford

Joseph John Thompson

Harold Urey

Charles T. R. Wilson

Rosalyn Yalow

Let us consider the case of Marie Curie. The following items are examples of some of the information described in the project.

Birth Certificate

Name: Marie Sklodovska

Date of Birth: 7 November 1867

Place of Birth: Warsaw, Poland

Sex: Female

Mother's Name: Bronislawa Boguska Curie

Mother's Occupation: School Teacher

Father's Name: Wladislaw Curie

Father's Occupation: School Teacher

Number of Brothers: 1

Number of Sisters: 4

School Record

1882 - Completed secondary school training in Warsaw, Poland

1891-93 - Attended the Sorbonne, Paris, France; Received Master's in Physics

1895 - Received Master's in Mathematics at the Sorbonne

1903 - Doctoral degree conferred by the Sorbonne

Letter Home

7 November 1892

Dear Mama and Papa,

School goes well especially now that I am able to give more time to my studies.

My dear sister Bronya was wonderful to provide a place for me to stay but with so many interruptions my studies were suffering. In a doctor's household there is always much activity! Also, the great distance from the Sorbonne meant that too much time was spent traveling.

Do not worry about me here. My room is small but adequate and is right next to the University. My hope is that the winter will not be too harsh this year - coal is so expensive.

I will return home this summer after completion of my Master's exam. My love to the family.

Your loving daughter,

Marie

Death Notice

CURIE, MARIE SKLODOVSKA

Died Thursday, 4 July 1934 of pernicious anemia believed to be a result of her work with radiation.

Born in Warsaw, Poland on 7 November 1867, a daughter of the late Wladislaw and Bronislawa Curie.

She was a teacher and researcher for many years at the Sorbonne and was the only person to be honored as the recipient of two Nobel Prizes - one in physics which she shared with Henri Becquerel and her husband Pierre and also one in chemistry. She is noted for the discovery of the elements polonium (named for her native country) and radium.

Mme Curie was active in the Great War with the operation of mobile X-ray units for the French Army as well as with training X-ray technicians.

She was preceded in death by her husband Pierre in 1906.

She is survived by two daughters, Irene Joliot-Curie and Eve Curie. Fellow scientist Albert Einstein said of Mme Curie that she was "the only person to be uncorrupted by fame".

Burial will be at Sceaux Cemetery.

References

Birch, Beverley. Marie Curie. Gareth Steven Publishing. Milwaukee, WI. 1988.

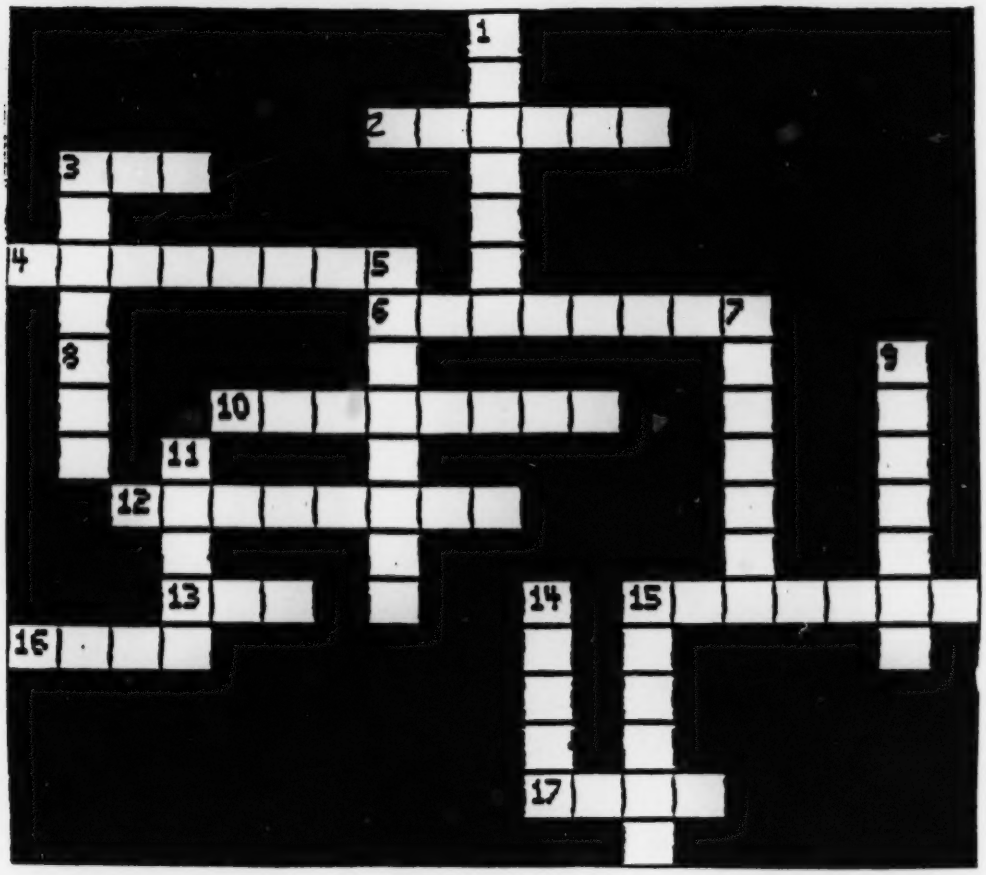
Greene, Carol. Marie Curie, Pioneer Physicist. Regensteiner Publishing. Chicago. 1984.

Nuclear Crossword Puzzles

by Richard M. Schwalm

Many students find that doing crossword puzzles is enjoyable. Teachers have found the puzzles to be a relatively painless way for students to review terms and concepts in science. The first two puzzles in the following collection may be used as a review of nuclear terms prior to a unit test, as a homework assignment or as an in-class assignment, perhaps when a substitute teacher needs additional ideas or when students request extra credit work. The crossword puzzle on nuclear history may be helpful as a starting point for a library project or report on important nuclear scientists. The names of the persons found in the answers may then be assigned or selected for further research and reporting. (Refer to **Researching Nuclear Scientists** by Sandra J. Parente in this booklet for creative ways to report on scientists.)

33



NUCLEAR TERMS # 1

ACROSS:

2. A POSITIVE SUBATOMIC PARTICLE
3. AN ATOM WITH AN UNBALANCED ELECTRICAL CHARGE
4. A POSITIVE BETA PARTICLE
6. THE SUBATOMIC PARTICLE THAT HOLDS A NEGATIVE ELECTRICAL CHARGE
8. THE LETTER WHICH REPRESENTS THE ATOMIC MASS
10. ATOMS OF DIFFERENT ELEMENTS THAT HAVE THE SAME 'N' NUMBER
12. THE AMOUNT OF TIME REQUIRED FOR ONE HALF OF THE ATOMS OF A RADIOACTIVE ISOTOPE TO DECAY
13. MILLION ELECTRON VOLTS ABBREVIATION
15. THE SPLITTING OF AN ATOM
16. RADIATION WHICH IS SIMILAR TO AN ELECTRON
17. THE SMALLEST PARTICLE OF AN ELEMENT THAT STILL HAS THE PROPERTIES OF THE ELEMENT

DOWN:

1. ATOMS WITH THE SAME 'Z' NUMBER BUT WITH DIFFERENT NUMBER 0F NEUTRONS
3. ATOMS OF DIFFERENT ELEMENTS THAT HAVE THE SAME 'A' NUMBER
5. A CHARGELESS, MASSLESS PARTICLE GIVEN OFF IN POSITRON DECAY
7. THE CENTER PORTION OF AN ATOM CONSISTING OF PROTONS AND NEUTRONS
9. A NEUTRAL SUBATOMIC PARTICLE
11. RADIATION FROM THE NUCLEUS WHICH IS IN THE FORM OF ELECTROMAGNETIC RADIATION
14. SUBATOMIC PARTICLE SIMILAR TO A HELIUM NUCLEUS
15. THE JOINING OF LIGHT NUCLEI TO FORM A HEAVIER NUCLEUS

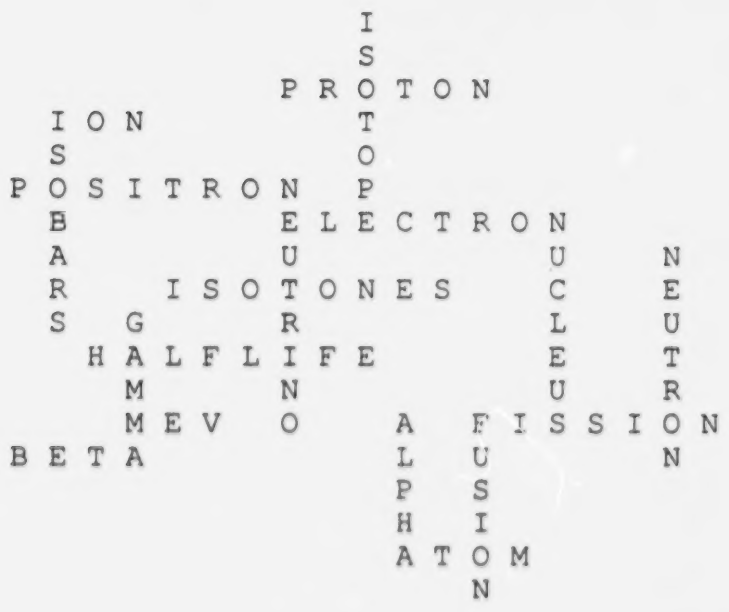
ANSWER KEY TO NUCLEAR TERMS #1

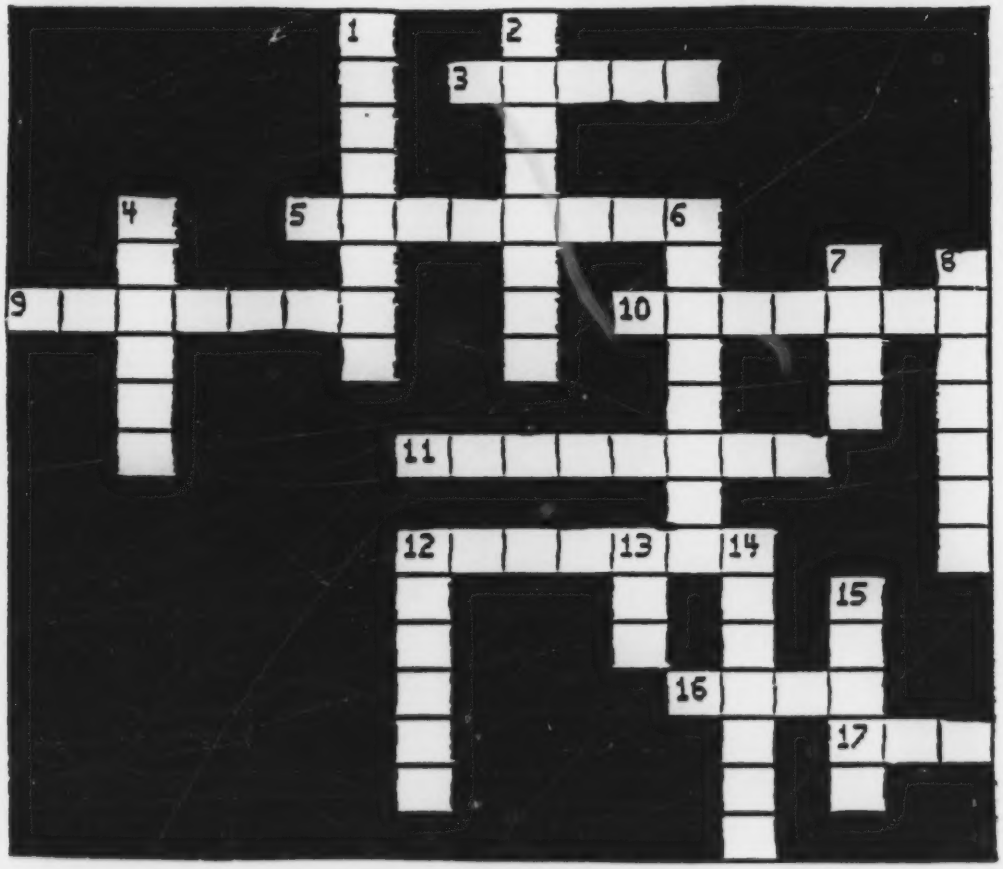
Across:

2. PROTON
3. ION
4. POSITRON
6. ELECTRON
8. A
10. ISOTONES
12. HALFLIFE
13. MEV
15. FISSION
16. BETA
17. ATOM

Down:

1. ISOTOPE
3. ISOBARS
5. NEUTRINO
7. NUCLEUS
9. NEUTRON
11. GAMMA
14. ALPHA
15. FUSION





NUCLEAR TERMS #2

ACROSS:

3. A PARTICLE IDENTICAL TO A HELIUM NUCLEUS
5. A POSITIVE BETA PARTICLE
9. ATOMS WITH THE SAME 'Z' NUMBER BUT WITH DIFFERENT NUMBER OF NEUTRONS
10. THE CENTER PORTION OF AN ATOM CONSISTING OF PROTONS AND NEUTRONS
11. THE AMOUNT OF TIME REQUIRED FOR ONE HALF OF THE ATOMS OF A RADIOACTIVE ISOTOPE TO DECAY
12. THE SPLITTING OF AN ATOM
16. THE SMALLEST PARTICLE OF AN ELEMENT THAT STILL HAS THE PROPERTIES OF THE ELEMENT
17. MILLION ELECTRON VOLTS ABBREVIATION

DOWN:

1. ATOMS OF DIFFERENT ELEMENTS THAT HAVE THE SAME 'N' NUMBER
2. THE SUBATOMIC PARTICLE THAT HOLDS A NEGATIVE ELECTRICAL CHARGE
3. THE LETTER WHICH REPRESENTS THE ATOMIC MASS
4. A POSITIVE SUBATOMIC PARTICLE
6. A CHARGELESS, MASSLESS PARTICLE GIVEN OFF IN POSITRON DECAY
7. RADIATION WHICH IS SIMILAR TO AN ELECTRON
8. ATOMS OF DIFFERENT ELEMENTS THAT HAVE THE SAME 'A' NUMBER
12. THE COMBINATION OF TWO LIGHT ELEMENTS TO FORM A HEAVIER ELEMENT
13. AN ATOM WITH AN UNBALANCED ELECTRICAL CHARGE
14. A NEUTRAL PARTICLE WITHIN THE NUCLEUS
15. VERY HIGH ENERGY ELECTROMAGNETIC RADIATION

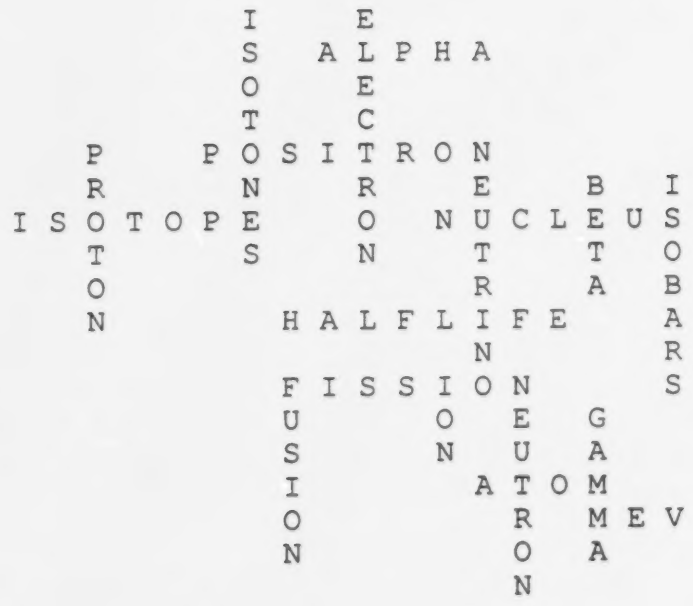
ANSWER KEY TO NUCLEAR TERMS #2

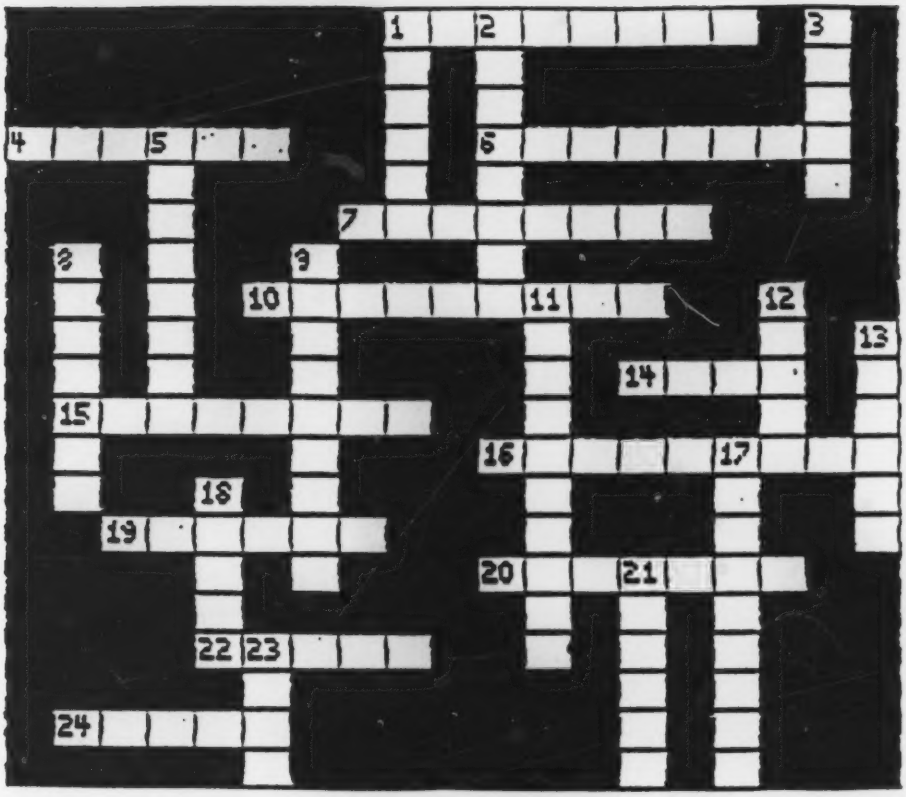
Across

3. ALPHA
5. POSITRON
9. ISOTOPE
10. NUCLEUS
11. HALFLIFE
12. FISSION
16. ATOM
17. MEV

Down

1. ISOTONES
2. ELECTRON
3. A
4. PROTON
6. NEUTRINO
7. BETA
8. ISOBARS
12. FUSION
13. ION
14. NEUTRON
15. GAMMA





NUCLEAR HISTORY

ACROSS:

1. 1863-1953 AMERICAN PHYSICIST WHO DETERMINED THE CHARGE ON THE ELECTRON (OIL DROP EXPT)
4. 1766-1844 CONSIDERED THE FATHER OF MODERN ATOMIC THEORY
6. 1845-1923 DISCOVERED X RAYS IN GERMANY IN 1895
7. 1706-1790 DEFINED POSITIVE AND NEGATIVE CHARACTER OF ELECTRICITY (KITE EXPT)
10. 1852-1908 FRENCH PHYSICIST WHO DISCOVERED RADIATION FROM URANIUM ON A PHOTO PLATE
14. 1885-1962 DANISH PHYSICIST WHO DEFINED THE STRUCTURE OF THE ATOM
15. 1879-1955 DEVELOPED SPECIAL AND GENERAL THEORY OF RELATIVITY
16. 1779-1848 SWEDISH CHEMIST WHO DETERMINED ATOMIC WEIGHTS FOR KNOWN ELEMENTS
19. 1882-1945 DEVELOPED THE GM TUBE
20. 1892-1962 WORKED WITH THE SCATTERING EFFECT OF X-RAYS AND ELECTRONS
22. 1867-1934 THE ONLY PERSON TO WIN TWO NOBEL PRIZES; NAMED THE ELEMENT POLONIUM
24. 1627-1691 DEFINED WHAT AN ELEMENT IS

DOWN:

1. 1878-1969 FEMALE AUSTRIAN PHYSICIST WHO DISCOVERED FISSION
2. 1901-1958 INVENTED THE CYCLOTRON
3. 1858-1947 GERMAN PHYSICIST WHO DEVELOPED QUANTUM MECHANICS
5. 1856-1940 BRITISH PHYSICIST WHO DISCOVERED THE NEGATIVE ELECTRON
8. 1831-1879 SCOTTISH PHYSICIST WHO DEVELOPED THE ELECTROMAGNETIC THEORY
9. 1834-1907 FORMED THE FIRST PERIODIC TABLE FROM THE 63 THEN KNOWN ELEMENTS
11. 1871-1937 THE FATHER OF NUCLEAR SCIENCE; NAMED ALPHA, BETA, AND GAMMA RADIATION
12. 1901-1954 DISCOVERED SLOW NEUTRONS AND HELPED BUILD THE FIRST NUCLEAR REACTOR
13. 1869-1959 SCOTTISH PHYSICIST WHO DEVELOPED THE CLOUD CHAMBER
17. 1743-1794 STATED THE LAW OF CONSERVATION OF MASS
18. 1902-1984 PREDICTED THE EXISTENCE OF ANTI-PARTICLES
21. 1751-1826 LAW OF DEFINITE PROPORTIONS
23. 1893-1981 DISCOVERED DEUTERIUM, AN ISOTOPE OF HYDROGEN

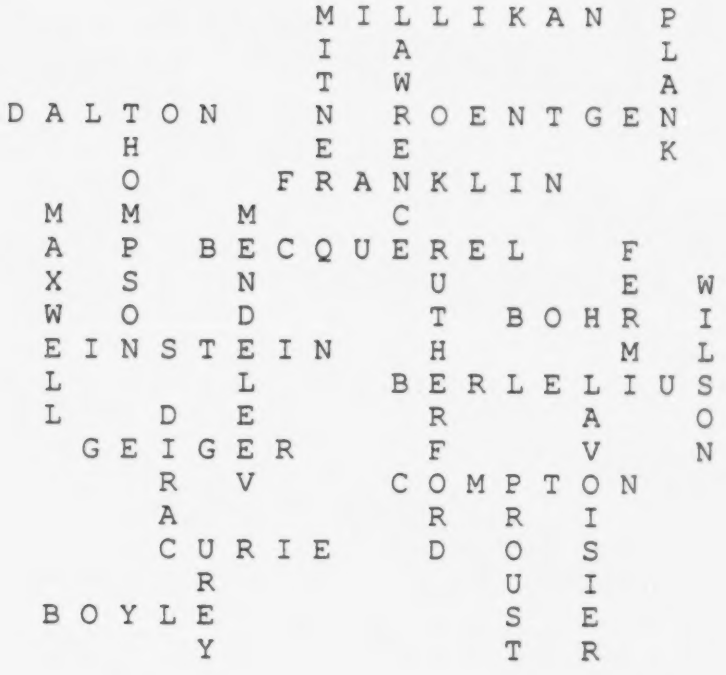
ANSWER KEY TO NUCLEAR HISTORY

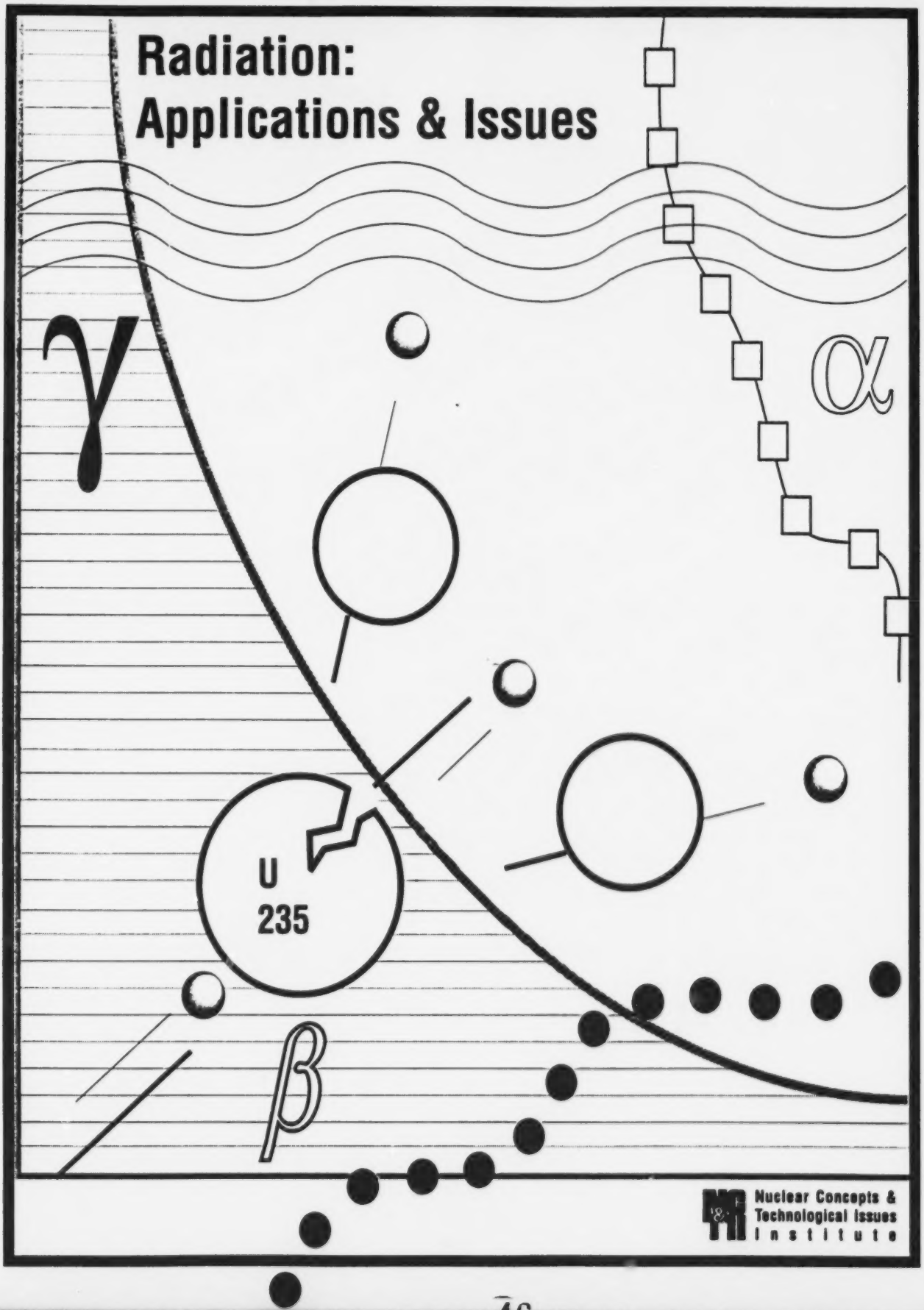
Across

1. MILLIKAN
4. DALTON
6. ROENTGEN
7. FRANKLIN
10. BECQUEREL
14. BOHR
15. EINSTEIN
16. BERZELIUS
19. GEIGER
20. COMPTON
22. CURIE
24. BOYLE

Down

1. MITNER
2. LAWRENCE
3. PLANK
5. THOMPSON
8. MAXWELL
9. MENDELEEV
11. RUTHERFORD
12. FERMI
13. WILSON
17. LAVOISIER
18. DIRAC
21. PROUST
23. UREY




Radiation:
Applications & Issues
γ
α
U
235
β
Nuclear Concepts &
Technological Issues
Institute

Relating Radiometric Age Dating to Relative Age, Absolute Age and the Geologic Time Scale

by David Calabrese

Background and Objectives: This activity was prepared for use in a ninth grade earth science course. The objectives are:

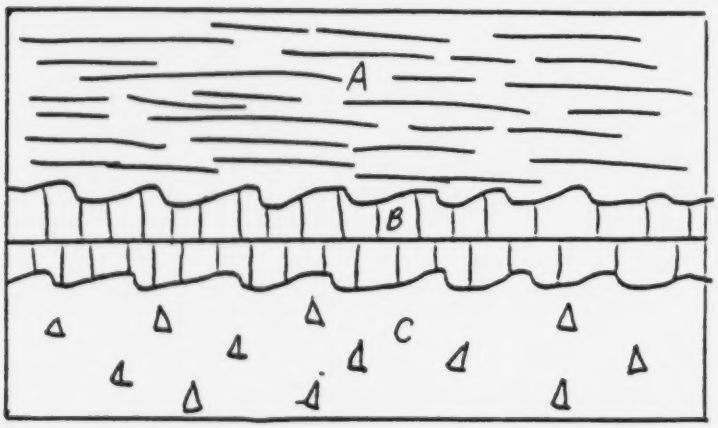
1. to compare and contrast relative age dating with absolute age dating;

2. to show how absolute dating is accomplished;

3. to show how absolute dating can be used to determine during what era, period, or epoch a geological event took place;

4. to demonstrate how a problem can be solved using two different methods: the law of superposition and radiometric age dating.

Data:



Top

A - peat

B - limestone with fossil corals

C - granite

Bottom

Stratigraphic Section

1 inch = 10 feet

Problems:

As a field geologist you mapped the stratigraphic section pictured above. Using the Law of Superposition (younger rocks are above older rocks if no deformation has occurred), you determined the relative ages of the units to be: layer A is the youngest, layer B is older than layer A but younger than Layer C, and layer C is the oldest. Your boss wants you to prove that you are correct so samples are taken from each layer and sent to a lab for radiometric age dating. Use the following half life information to answer the questions that follow.

$C^{14} \longrightarrow C^{12}$	C^{14}	half life is 5800 years
$U^{235} \longrightarrow Pa^{231}$	U^{235}	half life is 110,000,000 years
$K^{40} \longrightarrow Ar^{40}$	K^{40}	half life is 1.3 billion years

1. The lab determines that the C^{14} in the peat of layer A has undergone 4 half lives.

   a. How old is the peat?

   b. How much C^{14} is left in the layer?

2. Analysis reveals that 12.5% of the original U^{235} is still in the limestone of layer B.

   a. How many half lives has the U^{235} undergone?

   b. How old is the limestone?

3. The ratio of K to Ar in the granite of layer C is 25:75.

   a. How many half lives have occurred?

   b. How old is the granite?

4. Complete the chart:

layer	relative age	absolute age
A (peat)	youngest	_____ yrs.
B (limestone)	middle	_____ yrs.
C (granite)	oldest	_____ yrs.

5. Using a Geologic Time Scale and the absolute ages you calculated, answer the following:

   a. In what Era, Period, and Epoch was the peat deposited?

   b. In what Era and Period was the limestone deposited?

   c. In what Era was the granite deposited?

6. Why couldn't the granite be dated using C^{14} ?

7. Why couldn't the peat be dated using K^{40}?

8. When $C^{14} \longrightarrow C^{12}$, which is the parent? _____ the daughter? _____

9. The bones of what are thought to be a prehistoric human are found. Which type of radiometric dating would be used to determine the age of the bones?

References

Geologic Time Scale Zumberge and Nelson. 1976.

An Investigation of Radiation and Food

by Kathleen Hocker

This lesson plan is designed for an integrated chemistry/foods unit but can be used with either subject.

As an introduction to the lesson the demonstration table should have displayed on it the following: salt substitute, fresh and dried bananas, dried apricots, Brazil nuts, white potatoes, and strawberries, if available. Students should discuss (guess) why these items are on display.

Activity 1. "Jack in the Box" newspaper article. Article is displayed on the overhead projector, read by all, and discussed. Discussion question: What could have or should have been done to prevent the illness and death from eating contaminated meat?

Discussion should include the concepts of proper food storage, proper cooking (rate, temperature, time), health condition of the cooks, the environment, and the question of meat inspection. Introduce the idea of irradiation of the meat as a standard of quality assurance instead of visual inspection. This idea should bring out concerns about "radiation".

Activity 2 Pretest

Activity 3 Individually read "Good Food You Can't Get", Reader's Digest, July, 1993. Group discussion of the article. Include all ideas from the Radiation and Food Facts Sheets.

Activity 4 Individually read "Radioactivity in Food", pages SR-10 and SR-11 in the Student Reader section of Science, Society, and America's Nuclear Waste, Unit 2: Ionizing Radiation.

Individually complete the Radioactivity in Food Enrichment Activity on pages 119-121 of source noted above.

Activity 5 Measure the radioactivity of potassium in apricots, bananas, Brazil nuts, salt substitute, etc. Refer to Journal of Chemical Education, May, 1985, p. 439.

Activity 6 Project - Students choose one of the following activities as a culminating project.

Group Option - Prepare a Town Meeting or debate to discuss the advantages and disadvantages of food irradiation. Use source material to support positions.

Prepare, administer, and analyze a survey to ascertain people's insight and prejudices regarding food irradiation.

Research newspaper and magazine articles about food irradiation. Summarize and comment on at least five articles.

Write a newspaper article to convince people that irradiated food is safe and beneficial for human consumption.

Take a field trip to a Department of Health laboratory to investigate food poisoning outbreaks. Report on findings.

Investigate and write a report on the possible social/health benefits that food irradiation would have for a developing nation.

Radiation and Food Pretest

1. Food irradiation was first used

A) before 1200 B) early 1900s C) since 1990s

2. Irradiated food is safe to eat.

A) True B) False

3. An ordinary banana contains more radioactive material than irradiated wheat flour.

A) True B) False

4. All living or once-living organisms (humans, plants, animals) contain radioactive isotopes.

A) True B) False

5. When food is irradiated, the radiation passes through the food. No radiation remains in the food.

A) True B) False

6. The astronauts ate only heat sterilized food because it was safer.

A) True B) False

7. Irradiated food contains fewer vitamins and nutrients than conventionally preserved food.

A) True B) False

8. A person should always avoid anything connected with or related to radiation.

A) True B) False

9. Radioactive isotopes of potassium-40 and carbon-14 are found in the food we eat. Do you think we should eliminate these foods from our diets?_____Why or why not?

Radiation and Food: Fact Sheet

*The first food irradiation patents are issued in the United States and in Europe in 1905.

*An early goal of food irradiation research was to deliver fresh food to the troops in the fields during W.W.II. Storage and transportation were difficult and food needed to be preserved for lengths of time.

* Tests dating back to the 1950s show that irradiation kills bacteria and parasites that infect fish and shell fish and delays spoilage.

*The USDA approved irradiation as a method of sterilizing chicken, game hens and turkey in September of 1992.

* In 1992 the first U.S. commercial food irradiation plant opened in Florida and shipped irradiated strawberries to Miami, Seattle, Spokane, Pittsburgh, Rhode Island, Italy and France.

*Food irradiation is a common method of preservation in Europe, Israel, South Africa and 28 other nations.

* Food irradiation does not make the food radioactive.

* Controlled doses of radiation can destroy many bacteria that destroy food during storage.

* Food irradiation, rather than chemical preservatives, is being used to prolong the lifetime of many food items.

*For long-term storage food must be preserved to prevent spoilage. There are a variety of methods available. Heat treatment (cooking, pasteurizing, etc.) freezing, canning, or chemical treatments alter foods more than irradiation does. With irradiation fewer reaction products are found.

*Nutrients are lost in most preserving processes but these losses are usually higher in heated than in irradiated foods.

*Process of food irradiation:

- the food is exposed to ionizing radiation
- most of that radiation passes through the food
- some radiation interacts with the food by breaking down the cell walls of harmful microorganisms, resulting in the death of bacteria, molds, insects, and some insect larvae.

* Bacon is sterilized using Cs-137, Co-60, 5 Mev betas.

* Wheat flour is subjected to Cs-137, Co-60, 5 Mev betas to eliminate insect infestation.

* Treatment of white potatoes with Cs-137 and Co-60 results in sprout inhibition.

* Irradiation permits sterilization of foods (such as eggs) that cannot be visually inspected or disinfected in any other way.

* Radiation penetrates ALL parts of the food being irradiated.

* Meat is presently visually inspected. Contaminated meat may go undetected until an outbreak of food poisoning occurs. (as with Jack in the Box)

* In the U.S., there are between 40-80 million cases of food borne illnesses every year. Many of these can be prevented by irradiation.

*Federal Centers For Disease Control and Prevention estimate more than 20 million illnesses occur each year from food poisoning causing some 9000 deaths yearly.

*Salmonella, listeria, campylobacter and some other pathogens that cause most food poisoning can be destroyed with radiation.

*USDA has shown that irradiation kills 99.5 to 99.99% of salmonella in poultry.

* Irradiation can be a boon to farmers and transporters. Now, food is often harvested before it is ripened so it can be transported without spoilage. Sometimes it is then chemically ripened. Crops can be picked when ripe and irradiated. Irradiation provides a longer shelf-life or slower spoilage rate.

* Before fruit can enter the United States, it must be certified free of insect pests. Irradiation can safely replace chemical fumigants such as ethylene dibromide and methyl bromide.

* The possibility of irradiating pork to eliminate trichina is being studied. This would enable the US to export pork. Foreign countries will not accept contaminated pork.

*In the underdeveloped world 25-50% of food is lost to spoilage. Irradiation can reduce this loss and offset starvation.

* Irradiation is used to sterilize food used by the astronauts.

*Irradiation is used to sterilize foods given to persons with weakened immune systems such as those undergoing cancer treatment or organ transplant.

*Irradiation can be used to control insect and microbial infestations of spices.

*Special interest groups are campaigning against food irradiation.

*Numerous short and long-term safety studies that tested irradiated foods found no harmful effects.

*Years of studying irradiated foods has not led to the discovery of any "unique radiolytic products."

*Irradiation is also used to sterilize medical supplies and cosmetics.

*Radiation is used to gauge the thickness of egg shells.

*The water we drink contains radioactivity from radon decay products.

*The human body contains 130 billion radioactive atoms, mainly potassium and carbon.

*Many of the foods we eat are naturally radioactive.

*Radiation is natural. It is all around us. All living or once living organisms contain radioactive carbon 14.

*The Food Irradiation Symbol:

References

"Food Irradiation Approved by USDA" Re-actions. American Nuclear Society. Vol. 8. Nov. 1992.

Katzenstein, Larry. "Good Food You Can't Get" Reader's Digest. July 1993.

Kirchhoff, Sue. "Fast Food Illnesses Spur Upgrading of Meat Inspections". The Philadelphia Inquirer Feb. 6, 1993.

Norman, Jack C. "Potassium in Apricots - A Nuclear Chemistry Experiment". J. Chem. Educ. May 1985 Vol. 62 Number 5 p. 439.

Nuclear Chronicle. American Nuclear Society. 1992.

"Unit 2 - Ionizing Radiation" Science, Society, and America's Nuclear Waste. U.S. Dept. of Energy.

The Effects of Irradiation on Corn Seeds

by William N. Ulmer

Background: Different types of ionizing radiation (X-rays, cosmic, alpha, beta, gamma, etc.) interact differently with living tissue. Scientists have used this ability to study the effects on food preservation, pest control, medical procedures and in mutation breeding. In working with the ionizing radiation the experimenter must realize that he or she is composed of living tissue that could be affected by the ionizing radiation. In Homo sapiens a whole body dose of 450 RAD is usually lethal and a whole body dose of 50 RAD will cause blood changes. In working with gamma irradiated seeds there is no radiation danger since the process of such irradiation does not make the living material radioactive. (You don't become radioactive when you have an X-ray, for instance.) You will be working with the products of irradiation, not the process.

The most common type of ionizing radiation used for medical experiments is gamma because of its penetrating power. Cesium-137 and cobalt-60 are the most common radioactive isotopes used. You may know someone who has had cobalt-60 treatments for cancer. Cancer cells are actively dividing cells which makes them more susceptible to the ionizing radiation than are most normal body cells. If the radiation beam is narrow enough the cancerous tissue can be destroyed with minimal harm to normal tissue.

A cobalt-60 gamma source was used to irradiate the corn seeds used in the following experiment. The seeds were exposed to the cobalt-60 source at the Breazeale Nuclear Reactor on the University Park campus of The Pennsylvania State University. The gamma radiation interacted with the seeds but did not cause the seeds to become radioactive. Because seeds are dry and dormant the lethal dose is much higher than that for moist, actively dividing tissue. The dose of ionizing radiation to which the seeds were exposed may have had some effect on the seeds' ability to grow.

Purpose: As an inquisitive science student you want to know how much effect different dosages of radiation had on the growth of the corn seeds and whether an overall pattern of cause and effect can be determined. The following experiment may help you to arrive at a conclusion.

Procedure:

1. On your laboratory data sheet write your hypothesis regarding the effects of radiation dose on corn seed growth. (Hint: Will the radiation dose have no effect, help the growth or hinder the growth?)

2. Class teams will all use corn seeds but each team will use seeds exposed to a different radiation dose. Be sure to record the radiation dose given to your seeds.

3. One team will plant the control seeds. Those seeds made the trip to and from University Park but were not exposed to the gamma source.

4. The variable being tested in this experiment is radiation exposure dose. Therefore it is necessary to plant and treat your seeds in the same way as those of all the other teams.

    a. Count out 30 seeds to plant in the marked row in the planting container in the growth chamber.

    b. Evenly space the seeds along the row and cover them with 4 mm of soil.

    c. Label the row with your team's name and the radiation dose of the seeds.

    d. Check the soil daily and water when needed. The soil should stay moist.

Data:

1. Observe your experiment daily and record the per cent germinated and the average length in mm of your seedlings every Monday and Friday. Measure the length of the seedlings from the soil surface to the tip of the leaf. Use care in measuring, as your data will be combined with that of other teams to derive an answer to your hypothesis.

2. Continue growing the corn seedlings until one group develops a second rolled leaf. All groups then discontinue data collecting.

3. Record your team data on the class data sheet and, when all team data has been collected, record the class data onto your class data sheet.

Graphing:

1. Graph the class data, with the x axis for the independent variable, time in days. Start with zero and end with the last day the seedlings were measured.

2. Use the y axis for the dependent variable, average length of seedlings in mm. Start with zero and end with the largest number of mm in the class data table.

3. Plot data from each dose with a different colored pencil and specify which color represents which radiation dose.

4. Be sure to include a title to your graph.

Analysis and Conclusions: Study the graphs to look for patterns of results. Write up a lab report that includes title, hypothesis, materials, procedure, data, conclusion, sources of error, and new questions raised. Hand in your report and your graph.

Team Data Table - Dose: __RAD

Day													
Date													
% Germinated													
Av. Length of Seedlings in cm.													

Class Data Table

Day													
Date													
Dose													
Av. Length of Seedlings in cm.													

Using Beta Radiation to Determine Thickness

by Andrew C. Snyder

Background: The amount of radiation passing through an object depends on its density and its thickness. Consequently, radiation can be used to determine the thickness of an object if the density is known or if the density remains constant and several known thicknesses are measured. Although this may seem to be a complicated method for determining thickness, it has some useful industrial applications. For example, this technique can be used to monitor the thickness of a sheet of plastic as it is passing by on rollers; it provides a method for quality control without stopping the manufacture of the plastic.

Purpose: In this lab you will measure how radiation is shielded by notecards. After preparing a graph of the information, you will determine the number of notecards in a stack by measuring the amount of beta radiation that passes through the stack. This calculation will be compared with the actual number of cards. You should be able to explain why the beta source is used instead of the gamma or the alpha source.

Materials: Scalar, beta source (See Appendix B, Equipment Sources #2), 30 notecards, forceps.

Safety: The scalars use some very high voltages (10,000 V). Do not operate them with wet hands. Do not open the covers on the scalars or place anything inside them. The cover on the G-M tube is delicate; do not touch it. Handle all sources with forceps. Remove all sources from the detector when you are finished counting.

Procedure:

1. Make sure the scalar is on and the operating voltage is adjusted to the appropriate value.

2. With all sources away from the G-M tube, take a 1 minute background count.

3. Place the beta source on the second level and take a 1 minute count. If this count is above 8000, move the source and shelf down one level.

4. Place one notecard on top of the source and take a 1 minute count; record this under "counts per minute."

5. Add one notecard to the stack and take a 1 minute count. (Note: if you are running short of time, you may add notecards two at a time; be sure to record your data on the proper lines in your table.)

6. After removing all cards from above the beta source, take a small pack of card, without counting, place them in the scalar, and take a 1 minute count. Record this number, count the cards, and record the number of cards under "actual number of cards."

7. Place an alpha source on the second shelf and take a 1 minute count.

8. Cover the alpha source with one notecard and take a 1 minute count.

9. Place a gamma source on the second shelf and take a 1 minute count.

10. Cover the gamma source with 5 notecards and take a 1 minute count.

Calculations: 1. Subtract the background count from the counts per minute to obtain the adjusted counts.

2. Construct a graph of adjusted counts per minute vs. number of notecards. Use semi-log paper and plot the number of cards on the x-axis. Draw a best-fit line.

3. Use your graph to determine the number of notecards in your stack of cards.

4. Compare the calculated number of cards to the actual number of cards.

Questions: Answer all questions in complete sentences. Partial credit will be given for partial answers.

1. How did your actual number of cards compare with the calculated number of cards?

2. Why was it necessary to use the beta source for this experiment? (Use your data for the alpha and gamma sources in your answer.)

3. Suppose you had taken counts for ten minutes instead of one minute. How would this have changed your data?

4. A playing card company wants a method of making sure that all cards are included in their decks. However, they want to check this after the cards have been sealed in their packages. Would the method used in this experiment be a useful technique? Why or why not?

5. Suggest some possible additional applications of this technique.

6. Suppose you were measuring the thickness of some metal foils and you found that the foils blocked nearly all of the beta radiation. Which type of radiation would you try next--alpha or gamma? Why?

Directed Reading and Thinking Activity

by Linda K. Gardner

The Directed Reading and Thinking Activity that follows could be a class activity or an individual study project. I have indicated procedures for each.

This activity would be suitable for an Environmental Science class, a Science, Technology, and Society class, or an applied Chemistry or Biology class. The level of reading required would limit this activity to the eleventh or twelfth grade student.

Reading Assignment: "Living With Radiation". National Geographic, April 1989.

A. Establishing Background

Class Activity: An overhead of the following would be used to stimulate a discussion, which would serve as background for the reading assignment:

Individual Activity: The following are excerpts from the article; write on your sheet of paper what number, word or phrase you think completes the sentence. Do this prior to reading the article (points will not be taken off for incorrect answers!)

1. Almost all radioactive exposure -- some _____ percent in the U.S. -- comes from natural sources.

2. Man-made radiation --the other_____percent-- comes from everyday sources, primarily from _____.

3. Every_____ substance contains unstable atoms, or radionuclides. They change or decay into something more stable.

4. The energy of radiation moves _____ That helps account for the fear it instills.

5. He made a remark that, I have since learned, governs every aspect of living with radiation: "You're always balancing _____ against possible _____.

B. Building Vocabulary

Class Activity: The following words would be discussed before the students read the assignment:

Individual Activity: Hopefully, the above statements produced enough curiosity that you go on and read the article!! Before you start, define the following terms, so that reading the article will be more meaningful. On your answer sheet, jot down the meaning in your own words. If you are unsure of the meaning, look it up and write down the definition.

1. malignant
2. ingenuity
3. lethal
4. opinion
5. fact
6. incontestable

C. Establishing a Purpose for Reading Through Pre-questioning

Class Activity: This article contains excellent pictures, graphs and charts. These would be shared with the class prior to reading the article. Several questions would be asked to prompt a discussion and to engage the students prior to reading. (Examples of suggested questions: What is radiation? Is all radiation bad?)

Individual Activity: Okay- now you are ready to read the article! When you finish the article, go on to the rest of the activity.

D. Silent Reading

Class Activity and Individual Activity: The students should read the article.

E. Post Reading Questions

Class Activity and Individual Activity: The students would individually write answers to the following questions:

1. Does the United States conduct aboveground nuclear tests? Why or why not?

2. Why is radon gas a problem? (In answering this question, discuss if radon is man-made or natural, how it is and is not detected, what harm it presents to humans and what can be done about it.)

3. Do you think that the article gives equal time to both the risks and benefits of radiation? Give reasons for your answer.

4. Did this article give you a better understanding of radiation and its associated risks and benefits? Why or why not?

5. Do you think that the scientific community is in agreement with how much radiation is harmful? Why or why not?

F. Incorporating a Reading Skill

The reading skill emphasized during this activity is differentiating between factual based statements and opinion.

Class Activity and Individual Activity: The students would individually complete this activity by labeling the following statements "O" for opinion or "F" for fact.

Class Activity: This activity could be used to stimulate a class discussion to generate a consensus for each statement.

1. Said Dr. Karl Z. Morgan, an early pioneer in health physics, "It is incontestable that radiation risks are greater than published."

2. ..."Still, it seems unwise to completely dismiss Dr. Gofman's findings. Radiation standards are still evolving. A variety of studies hint that radiation-exposed workers may be more at risk than previously thought. And, in this inexact science, it seems that minority voices have been more right than wrong."

3. "Even here in the United States, where nuclear power seems stalled, it is second only to coal as a source of electrical energy, supplying 18 percent."(Ed. note: now supplying over 21%)

4. "Produced by radium decay in soil, radon cannot be seen, smelled, or felt."

G. Enrichment

Class Activity and Individual Activity: The following could be done on an individual or group basis.

Pick one of the following and do it, then attach it to your answer sheet:

1. Clip an article from a recent newspaper or magazine that concerns a risk or benefit associated with radiation.

2. List the name and location of all licensed nuclear plants in you state.

3. Write a brief report listing the benefits of nuclear energy.

4. Do a project of your choice-- as long as it is pertinent to nuclear concepts.

Low Level Radioactive Waste Activities

by James R. Young

The school in which I teach is located very near a proposed low level radioactive waste disposal site. The following activities may be included in lessons to address the low level radioactive waste issue so that the students will be able to make an informed decision concerning their future and nuclear energy.

Brief Outline of Activities

I. Radioactive isotopes and their emissions

A. Uranium Decay Series Game (alpha, beta, and gamma decay)

B. Equations of nuclear decay

C. Background radiation

II. The effects of distance and shielding from radioactive material.

III. The effect of time - half-life of radioactive material

IV. The importance of containment and survey of low level radioactive waste

V. Culminating activities

I. Nuclide Chart Familiarization - Uranium Decay Series Game (modification of The Radioactivity Game[6])

The students work in groups of four (4), two (2) per team, choosing team names to build involvement and excitement. The students roll a die and move tokens on the nuclide charts to demonstrate decay of Uranium-238 to stable Lead. The roll of a 5 or 6 designates alpha emission; rolling a 2, 3, or 4 designates beta emission; gamma emission is designated by a roll of the number 1. The students write balanced nuclear equations after each movement of the token. This must be done before the next roll. The possibility of not being able to move due to the need for a particular roll number approximates the rate of particle or ray emission. Upon completion of the contest (the first team to reach stability) the winners write the decay chain equations on the board while the others are completing their game.

Follow-up activity - discussion about the time involved for each type of move in the decay series and how it relates to actual decay times.

Questions:

1. What are the emissions given off during the decay series?

2. Where do these emissions go?

3. Where does the Uranium-238 come from?

4. What is an isotope? How many isotopes were in this decay series?

5. Is this decay chain going on in nature?

6. What elements in the decay series are you familiar with?

7. Is there radiation in the background?

Background Radiation

Use Sources and Doses of Radiation [5] as a hand out to discuss sources and doses of radiation. Emphasis on natural radiation will lead to discussion of soil and radon. "Radon - an odorless invisible gas that is heavier than air. Radon is emitted by uranium and thorium in soil and rock around the earth." [2] Thorium in the beach sand produces radon. Discuss the fact that the daughter products of radon are the real problem; should they be taken into the lungs in particulate form, they may lead to cancer.

Demonstration of Background Radiation: Using the Geiger-Muller counter, detect the levels of radiation and chart the same of common everyday items. Ex: sand, bottom of sand-filled tape dispenser, radium dial clock, mantles for Coleman lanterns, Fiesta ware (if available), brick, soil, TV screen, smoke detector, etc.....

II. Effects of Distance and Shielding: During the above demonstration the students may possibly make the observation that distance from the objects makes a difference in the counts and that simple shielding blocks the radiation and lowers the counts. If this observation does not come out in the follow-up discussion, demonstrate again making this point more obvious. This leads into the two laboratory investigations concerning Distance and Shielding [3].

III. Time: Half-Life Activity

Begin this section with a simple definition of half-life. Continue to discuss half-life in reference to low level radioactive waste. "Low level radioactive waste contains radioactive elements with low hazard levels and fast decay rates.. Overall the danger from LLW is not great."[1]

Activity: M&M Half-life (See Appendix A, Additional Activities)

Students work in groups of four: one person to shake 100 M&Ms, two to separate them into two groups (printed M&M side up and plain side up) and the fourth person to chart the count. Continue to shake, count, and record only the M&Ms with printed side up. Each group will graph the data collected as # M&Ms vs. # of shake. Compare graphs and data. Combine total class data and graph again. Does this make a difference? Forceps may be used to handle the M&Ms with printed side up and not for the plain side up to simulate handling of radioactive material.

IV. Containment and Survey

Students in groups of two are given a small piece of fluorescent chalk to crush in a mortar with a pestle. Half of the powdered chalk is placed on a piece of paper. The other half is placed in a test tube with five (5) ml. of water (to be used later). Using an ultraviolet light only, students check to see the amount of contamination in the work area and on the students caused by inadvertent spillage of the chalk. Discuss containment to work area, room, building, and means of prevention of spread. Have the students clean up their work area making sure that the wet paper towels used are placed in specially marked waste containers, as a simulation of proper radioactive waste disposal.

Questions:

1. How does this exercise simulate radioactive waste? What type? (high or low level?)

2. What do we do with the water and towels that have become contaminated?

3. Why should the cleaned work areas and students' hands be rechecked with the ultraviolet light?

Using the test tubes containing the powdered chalk and water mixture, pour the contents onto soil in an ant farm apparatus. Add more water to simulate rain. Check the sides of the ant farm with the ultra-violet light to trace the movement of the contaminant.

Discuss the possible contamination of ground water, wells, and biological effects. Follow with a discussion of containment methods.

V. Culminating Activities

Students in groups of three (3) support the siting of a LLRW site in our area against a group of three students representing the opposing view. Ask each side to support their stand with facts. Then have the students reverse roles.

Individual students prepare an essay of at least two (2) pages on "What I've Learned About LLRW" or "What I Think About a LLRW Site Nearby", or some other suitable topic concerning low level waste.

References

1. Dolan, Edward F. and Margaret M. Scariano. Nuclear Waste - The 10,000 Year Challenge. Franklin Watts. New York. 1990. pp. 38, 39.

2. Mims III, Forrest M., Ed. "Experimenting With a Geiger Counter". Science Experimenter Science Probe July 1992. pp. 102,103.

3. Murphy, James T. Laboratory Physics. Charles C. Merrill. Columbus, OH. 1982. pp.233, 234, 237, 239, 240, 241, 243.

4. Notes from Nuclear Concepts and Technological Issues Institute. Candace Davison, Joe Bonner, Rodger Granlund, Dr. Warren Witzig, et al. July 1993.

5. "Sources and Doses of Radiation". National Council on Radiation Protection and Measurements

6. The Radioactivity Game, Nuclear Energy Student Activities, Rev. Ed. 1988, New York Energy Project, Albany, NY. The gameboard, instructions, booklet of activities and supplement are available for $4.00 from: New York STS Education Project, 89 Washington Ave., Room 678, EBA, Albany, NY 12234

Radon Testing Activities for High School Science Classes

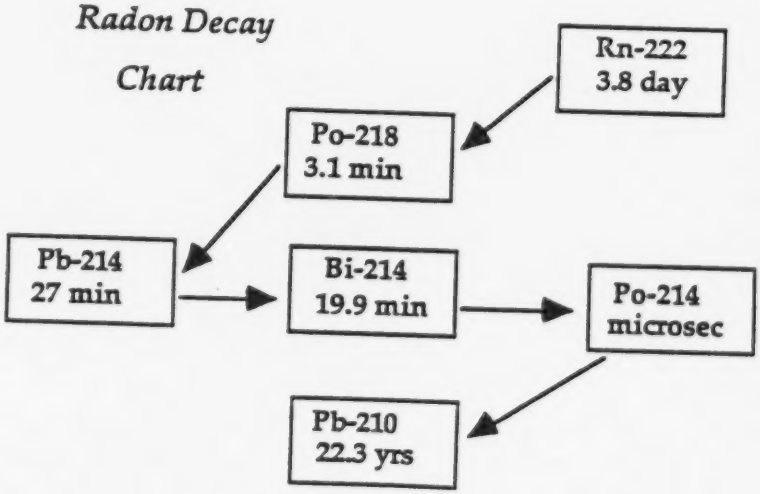
by Candace C. Davison, Mary Lou Dunzik Gougar and Ronald A. Matchock

A discussion and activities concerning radon gas can fit easily into most high school science classrooms, from biology to physics. Here we provide some background information, some ideas for classroom activities, and some references for further information.

Background:
Radon gas comes from the natural breakdown (radioactive decay) of uranium. Radon can be found in high concentrations in soils and rocks containing uranium, granite, shale, phosphate and pitchblende. In outdoor air, radon is diluted to such low concentrations that it is usually nothing to worry about. However, once inside an enclosed space (such as a home) radon can accumulate.

Radon itself naturally breaks down and forms radioactive decay products which are solid particles (See decay chart). These radioactive decay products are sometimes referred to as radon daughters or radon progeny. The main health concern with radon is not the gas itself, but the solid radioactive decay products. As you breathe, the radon decay products can become trapped in your lungs. As these decay products break down further, they release small bursts of energy which can damage lung tissue and possibly lead to lung cancer.

Radon Decay Chart



For further information sources, you may wish to contact the US. Environmental Protection Agency which publishes booklets by the following titles:

A Citizen's Guide to Radon
Home Buyer's and Seller's Guide to Radon
Radon in Schools
Radon: A Physician's Guide
Consumer's Guide to Radon Reduction
Technical Support Document
Application of Radon Reduction Techniques for Detached Houses
Radon Measurement in Schools
Radon Prevention in the Design and Construction of Schools and Other Large Buildings

Your state government will have a radon office from which you can obtain these E.P.A. booklets and further state-published information. The Pennsylvania State radon contact number is 800 - 237 - 2366. Speakers and other information may be obtained from the contacts listed on the resource page included with this activity.

"He was killed driving to the store to get a radon gas test kit."

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Activity # 1 Collecting Radioactive Particles from the Air
(Radon Daughters)

Objectives:

1.To show that radioactive particles are present in our air

2.To show the effect of collection/concentration in sampling

3.To lead into discussion of radon decay products and their potential health effects

Materials needed:

1. Electricity
2. Filter paper (a coffee filter will do)
   Note: keep in plastic bag or envelope until ready to use
3. Vacuum cleaner
4. Geiger counter (with pancake probe if possible)

Demonstration:

1. Take filter paper out of bag (envelope).
2. Turn on Geiger counter and use probe over the filter to demonstrate that the filter does not start out with radioactive material on it.
3. Place filter paper over vacuum cleaner inlet hose.
4. Turn on vacuum cleaner and let run for at least 5 minutes.
5. Shut off vacuum cleaner and remove filter from hose. Show the group the dust that was collected on the paper.
6. Use Geiger counter probe to detect if any radioactive particles were collected with the dust. Note approximate level of radioactivity for later comparison.
7. Put the filter in a bag or envelope and set aside for approximately one hour.
8. Test the filter paper again to see if the same level of radiation is being emitted from the filter paper.

Advanced demonstration:

Using a simple Geiger/scalar equipment - one minute counting measurements can be taken at five minute intervals and the counts recorded. This data can then be graphed and the half-life of the radon decay products (collectively) can be determined.
Using a sodium-iodide crystal and multi-channel analyzer one can determine the radon decay products by the energy of the gamma rays emitted. If the efficiency of the detector for the given geometry and gamma ray energy is known, then the activity of the radon decay products can be determined.

Possible Pitfalls:

1. If the filters are not kept in a sealed envelope or bag they can collect radon decay products from the air before use.

2. In areas of high humidity or upper levels of a building the radon concentration (and therefore radon daughter concentration) may be too low to detect.

Discussion:

1. Where did the radioactive particles come from? Were they caused by the vacuum cleaner? *They were present in the air, but vacuum cleaner pulled a large volume of air through a filter and concentrated the particles on the filter.*

2. What would you expect if the vacuum cleaner were run for 10 minutes instead of 5 minutes? *Double the volume of air would have passed through the filter, therefore more particles would be collected.*

3. Why was there less activity on the filter after it sat for 45 minutes? *Radon decay products have a short half-life (chart) therefore the daughter products were decaying away.*

Activity # 2 "Radioactiveball"

This experiment is a variation on Activity #1 in which radon daughter products are collected. Here the method of collection is based on the charge attraction between the radioactive particles in the air and a racquetball. The article, "Radioactiveball", in which this experiment was published can be found in Volume 30, the January 1992 edition, of The Physics Teacher magazine.

Activity # 3 School/Community Testing

A classroom project on radon testing could become a school or community service project.

Objectives:

1. To test different locations in your school or community for radon levels.

2. To show the effect of different variables on the testing process.

3. To provide data for a discussion on experimental variables and risks due to radon.

Materials needed:

1. Radon test kits - number and type will vary with your level of funding.

Radon testing kits may be obtained from your local hardware store and a variety of other sources. You can contact your state radon office which may have a discount or free service available to schools who do testing for educational purposes. Your local university may also have a program which would, for a set fee, send you a number of test kits, determine the results of the tests upon their return, and send you the data.

2. Testing sites - chosen based on class discussion and test kit criteria

Procedure:

1. Discuss with the class the movement of radon into buildings and the relative concentrations inside and outside a building and also within the building itself. Based on this discussion, choose test placement locations and have students predict the relative results of the testing.

2. Have students place radon testing devices (a charcoal canister, for example) at various predetermined locations around the school. After the prescribed exposure time, the devices will have to be sent to a laboratory for processing and the results will be returned. Upon obtaining the results, make a data table of the class results or plot the results on a map of the school to show representative radon levels. Your state may have a protocol for school testing. If this protocol is followed, your class may be able to provide official results to school administrators to save them a separate testing process. (See page 2 source list "Radon Measurement in Schools")

or

3. Provide each student in a class with a radon test kit and have the students test their homes or the homes of other volunteer family members in the community. Upon obtaining the results, make a data table of the class results or plot the results on a map of the community. This process can be repeated from year to year and the results plotted on the same map.

Possible Pitfalls:

1. Many variables can effect the results of radon testing. The test kit itself will suggest the best locations and conditions for that particular test. However, it is important to note that a change in time of the year (weather conditions), location in a building (basement or top floor), and level of ventilation (windows open/closed, AC on/off) can provide drastically different results.

2. Practical considerations of cost of the test kits and time to obtain results may make lesson plan coordination difficult. This project may have to be spread among several weeks or months amidst other topics.

Discussion:

1. How does the data received compare to the predicted results? What might be the reason(s)? *Many factors can effect the results including those listed in #1 above. Another factor may be not specifically following the test kit directions. Some tests are more sensitive than others.*

2. How do the results from the individual locations compare to each other? *This discussion should lead, once again, to the factors mentioned in #1 "Pitfalls" and #1 " Discussion".*

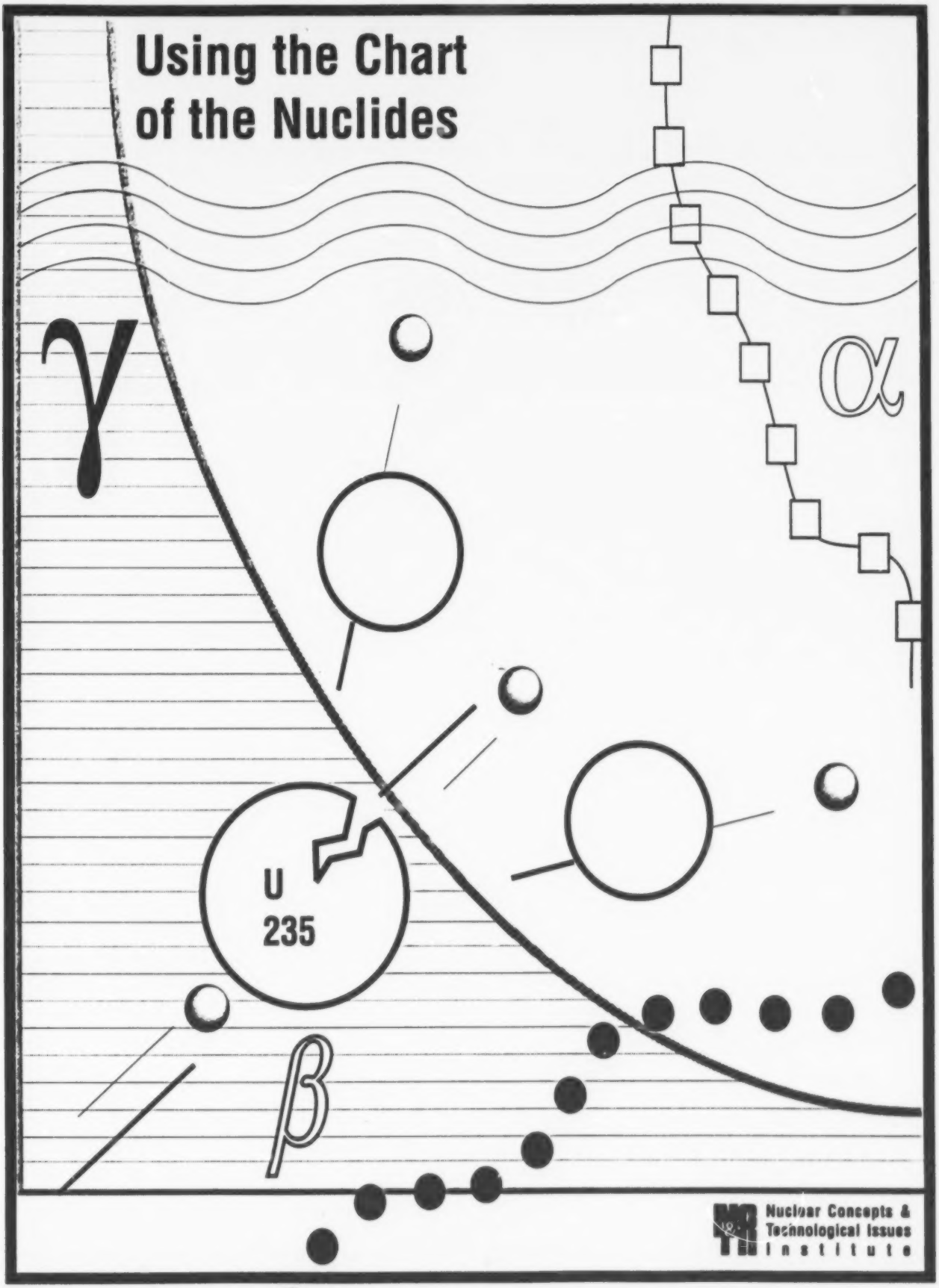
References

"Collecting Radioactive Particles from the Air" written by Candace C. Davison

"Radon Activity" edited by Mary Lou Dunzik Gougar, adapted from an activity by Ronald A. Matchock

For questions and further information, contact Candace C. Davison,
Breazeale Reactor, Pennsylvania State University, University Park, PA, 16802.
Phone: 814 - 865- 6351

Using the Chart of the Nuclides



Nuclear Concepts & Technological Issues Institute

The Chart of the Nuclides - Work Sheet

by Marianne Barker

Use the Chart of the Nuclides (See Appendix B, Information Sources #1) to answer the following questions. Be prepared to back up your answers with your reasoning.

1. How many isotopes of magnesium are there?

2. How many stable isotopes of cerium are there?

3. Name two stable isotopes of zirconium.

4. How many naturally occurring, radioactive isotopes of samarium are there?

5. Which nuclides of mercury have isomers?

6. Name seven isotones with 108 neutrons.

7. Name ten isobars with mass number 122.

8. What is the percent abundance of Te-128?

   What is the percent abundance of Te-130?

9. What is the half-life of Po-206?

10. By which mode will the following nuclides most likely decay?

Ga-70	Zn-63
No-257	Pd-98

11. Name ten nuclides which are possible fission products of U-235, U-233, or Pu-239.

12. If you had to be locked in a sealed room with one gram of radium for a day, with which nuclide would you be safest?

    Why?

13. If you had to be locked in a sealed room with one gram of plutonium for a day, with which nuclide would you feel most insecure?

    Why?

14. Which nuclide of thulium has the greatest probability of absorbing neutrons?

    Evidence?

15. When the following radioactive nuclides decay, what will be their daughters?

    Eu-148

    Ce-148

    Sm-133

    Ce-137

    No-256

16. Which isotopes of polonium have half-lives between 100 days and 10 years?

17. Which isotopes of protactinium have half-lives between ten and 100 days?

18. Which element has the largest number of stable nuclides?

19. Which element has the largest number of radioactive nuclides?

20. What is the "lightest" nuclide found as a fission product of U-235?

21. Which element has the "heaviest" nuclide found as a fission product of U-235?

22. Which nuclide of arsenic would be the most likely you'd use if you wanted to poison someone's food?

    Why?

23. Which nuclide of lead would be <u>least</u> likely to cause classical lead poisoning if ingested?

    Why?

24. Would the nuclide in question 24 be dangerous to ingest if it did not cause lead poisoning?

    Why or why not?

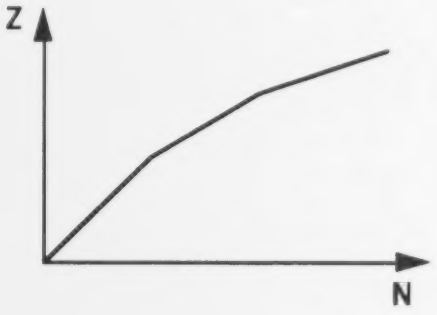
25. Describe general areas on The Chart of the Nuclides where radioactive decay is predominantly:

alpha, α

beta minus (negatron), β^-

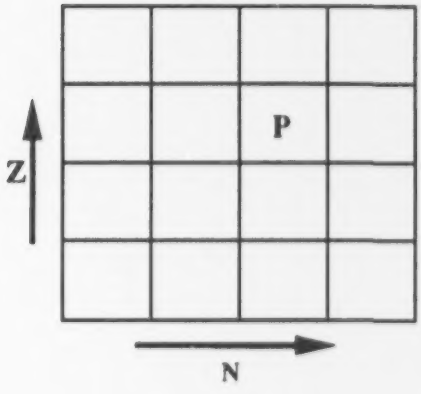
beta plus (positron), β^+

electron capture, ε

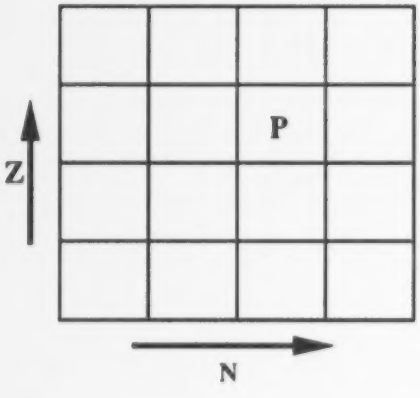


26. Pretend the boxes shown below are part of the chart of nuclides. Place a 'D' in the box where the daughter would be found with respect to the parent for each type of decay shown.

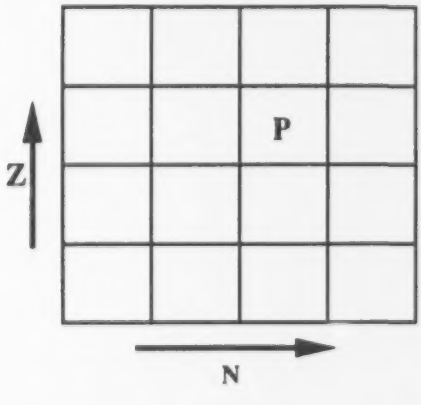
alpha decay



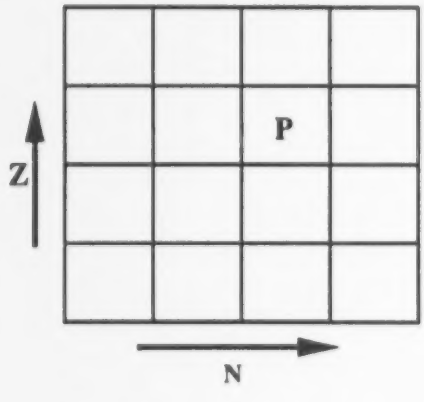
beta minus decay



beta plus decay



electron capture



The Chart of the Nuclides - Work Sheet Answers

by Marianne Barker

Use the Chart of the Nuclides to answer the following questions. Be prepared to back up your answers with your reasoning.

1. How many isotopes of magnesium are there? *15*

2. How many stable isotopes of cerium are there? *4*

3. Name two stable isotopes of zirconium. *Zr 90 (has 2 isomers, 1 is stable); Zr 91, Zr 92, Zr 94, Zr 96*

4. How many naturally occurring, radioactive isotopes of samarium are there? *3*

5. Which nuclides of mercury have isomers? *Hg 185, Hg 187, Hg 189, Hg 191, Hg 193, Hg 195, Hg 197, Hg 199*

6. Name seven isotones with 108 neutrons.
   Po 192, Pt 186, Au 187, Hg 188, Tl 189, Pb 190, Bi 191

7. Name ten isobars with mass number 122.
   Ag 122, Cd 122, In 122, Sn 122, Sb 122, Te 122, I 122, Xe 122, Cs 122, Ba122, La 122

8. What is the percent abundance of Te-128? *31.70%*

   What is the percent abundance of Te-130? *33.87%*

9. What is the half-life of Po-206? *8.8 days*

10. By which mode will the following nuclides most likely decay?

    Ga-70 β^- *(negatron emission)* Zn-63 β^+ *(positron emission)*

    No-257 α *(alpha emission)* Pd-98 ϵ *(electron capture) or* β^+

11. Name ten nuclides which are possible fission products of U-235, U-233, or Pu-239.
    any isotopes with a black triangle in the bottom right corner of the square, e.g. Sb 136, Te 136, I 136, Xe 136, In 132, Sn 132, Sb 132, Te 132, I 132, Xe 132

12. If you had to be locked in a sealed room with one gram of radium for a day, with which nuclide would you be safest? *Ra 226 (Note: specific activity of 1 gram of Ra is 1 Curie)*

    Why? *Ra 226 has the longest half-life, 1.60 x 10^3 years and decays by emitting alphas, which are easily shielded. Radon and other radioactive nuclides result, however.*

13 If you had to be locked in a sealed room with one gram of plutonium for a day, with which nuclide would you feel most insecure? *Pu 233*

    Why? It has the*shortest half-life (20.9 min.), and decays by electrn capture (as well as by alpha emission that is easily shielded).*

14. Which nuclide of thulium has the greatest probability of absorbing neutrons? *Tm 169*
Evidence? *Its σ value is biggest (highest neutron absorption x-section , 1.70 x 10 3 barns)*

15. When the following radioactive nuclides decay, what will be their daughters?
Eu-148 *Sm 148, Nd 144, Ce 140*

Ce-148 *Pr 148, Nd 148*

Sm-133 *Pm 133, Nd 133, Pr 133, Ce 133,*

Ce-137 *La 137, Ba 137, La 133, Ba 133, Cs 133*

No-256 *Fm 252; Cf 249; Cm 244, Pu 240, U 236; Th 232; Ra 228; Ac 228; Th 228; Ra 224; Rn 220; Po 216; Pb 212; Bi 212; Po 212; Pb 208.*

16. Which isotopes of polonium have half-lives between 100 days and 10 years?
Po 208; Po 210
17. Which isotopes of protactinium have half-lives between ten and 100 days?
Pa 230; Pa 233
18. Which element has the largest number of stable nuclides? *Sn (has 10)*

19. Which element has the largest number of radioactive nuclides? *In (has 32)*

20. What is the "lightest" nuclide found as a fission product of U-235? *Cu 72 (has smallest number of protons); or , better, Zn 72 (has smallest number of neutrons)*

21. Which element has the "heaviest" nuclide found as a fission product of U-235? *Er 167; Ho 167; or Dy 167 (since neutrons are slightly heavier than protons, the best answer is Dy 167.)*

22. Which nuclide of arsenic would be the most likely you'd use if you wanted to poison someone's food? *As 78 or As 70*

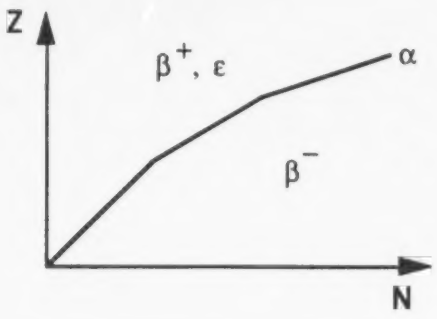
Why? *You'd have enough time to obtain and administer the nuclide, yet it would decay away before an autopsy would probably get done (within 24 hours)*

23. Which nuclide of lead would be <u>least</u> likely to cause classical lead poisoning if ingested?
Pb 182
Why? *Its half life (0.06 s) means it would decay away before it could cause much damage.*

24. Would the nuclide in question 24 be dangerous to ingest if it did not cause lead poisoning?
Yes.
Why or why not? *It emits alphas, depositing lots of energy in a very short time, causing localized cell damage.*

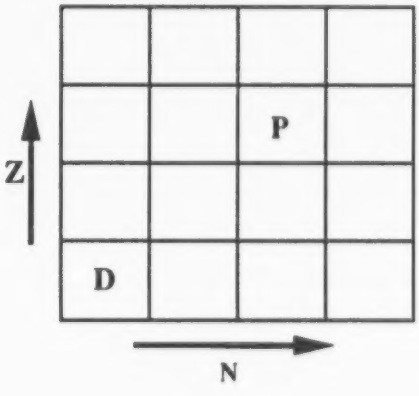
25. Describe general areas on The Chart of the Nuclides where radioactive decay is predominantly:

alpha, α
beta minus (negatron), β^-
beta plus (positron), β^+
electron capture, ε

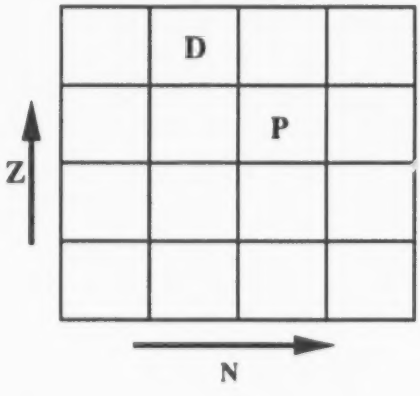


26. Pretend the boxes shown below are part of the chart of nuclides. Place a 'D' in the box where the daughter would be found with respect to the parent for each type of decay shown.

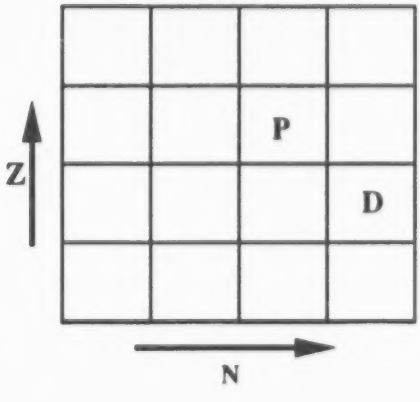
alpha decay



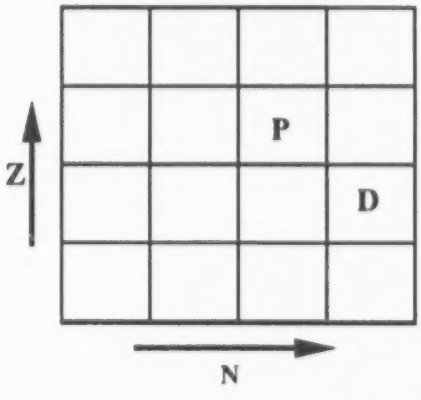
beta minus decay



beta plus decay



electron capture



179 Ways to Make Gold

by Sister Marilyn McCusker, S.C.C.

Introduction:

This project is built around a light-hearted look at the ancient art of alchemy. The alchemists of old eventually had to abandon their quest to change "dross" metal to gold; it could not be done by chemical means. However, it can be and has been done by means of nuclear bombardments.

The following "179 ways to make gold" are derived from the table "Displacements Caused by Nuclear Bombardment Reactions" on page 18 of The Chart of the Nuclides. (See Appendix B, Information Sources #1.) This project uses the chart merely as an exercise. No claim is made about the practicality, efficiency or economic feasibility of such procedures!

Certain rules or limitations have been adopted:

1. The starting nuclide must be a stable nucleus. The stable nuclides within three steps of Gold 197 have been marked on the chart in figure 1.
2. The transmutation must be done in the smallest number of steps. This rule limits the number of equations; however, several different processes are possible for a given starting nuclide.
3. If more than one step is needed to obtain gold, intermediate nuclides must not be stable.
4. The process has been limited to starting nuclides that require at most three steps to make gold. The chart (fig. 1) identifies all stable nuclides up to five steps from Gold-197.

Materials Included:

1. Computer program: GOLD, which takes data in coded form and creates a data base of 179 records, corresponding to the 179 possible ways to make gold by the bombardment of nuclides within three steps of gold. (Where a particle appears to be missing on either the left or right side of an equation, write in the symbol for gamma rays, γ.)

2. Computer program: WRTGOLD, which simply prints the equations from the data base in a good format. This list of equations is used as a reference for Activity #3, Gold Dig.

3. Let's Make Gold: Activity #1. This is a very basic activity in the form of a worksheet. It is designed for review of balancing nuclear equations. An equation or set of equations is printed with one nuclide or particle replaced by a rectangular box. The student must supply the contents of the box.

4. Gold at the End of the Rainbow: Activity #2. This is an intermediate activity designed also for practice. It gives the starting nuclide followed by one or more sets of bombarding and ejected particles. The student must write the balanced nuclear equation(s).

5. Gold Dig: Activity #3 This is an advanced activity in the form of a card game. The purpose of the activity is practice in using the Chart of the Nuclides and the table "Displacements Caused by Nuclear Bombardment Reactions". Directions for the game are included in addition to the cards needed. Element cards are the starting stable nuclides. These cards contain the number of steps needed to reach Gold-197. Particle cards contain one particle which is either a bombarding particle or an ejected particle, or a group of particles that is ejected.

The programs generated to create the data base and the activities could, with very little modification, be used to provide a more universal sampling of nuclides undergoing single bombardment reactions. But making gold was fun!

179 Ways To Make Gold

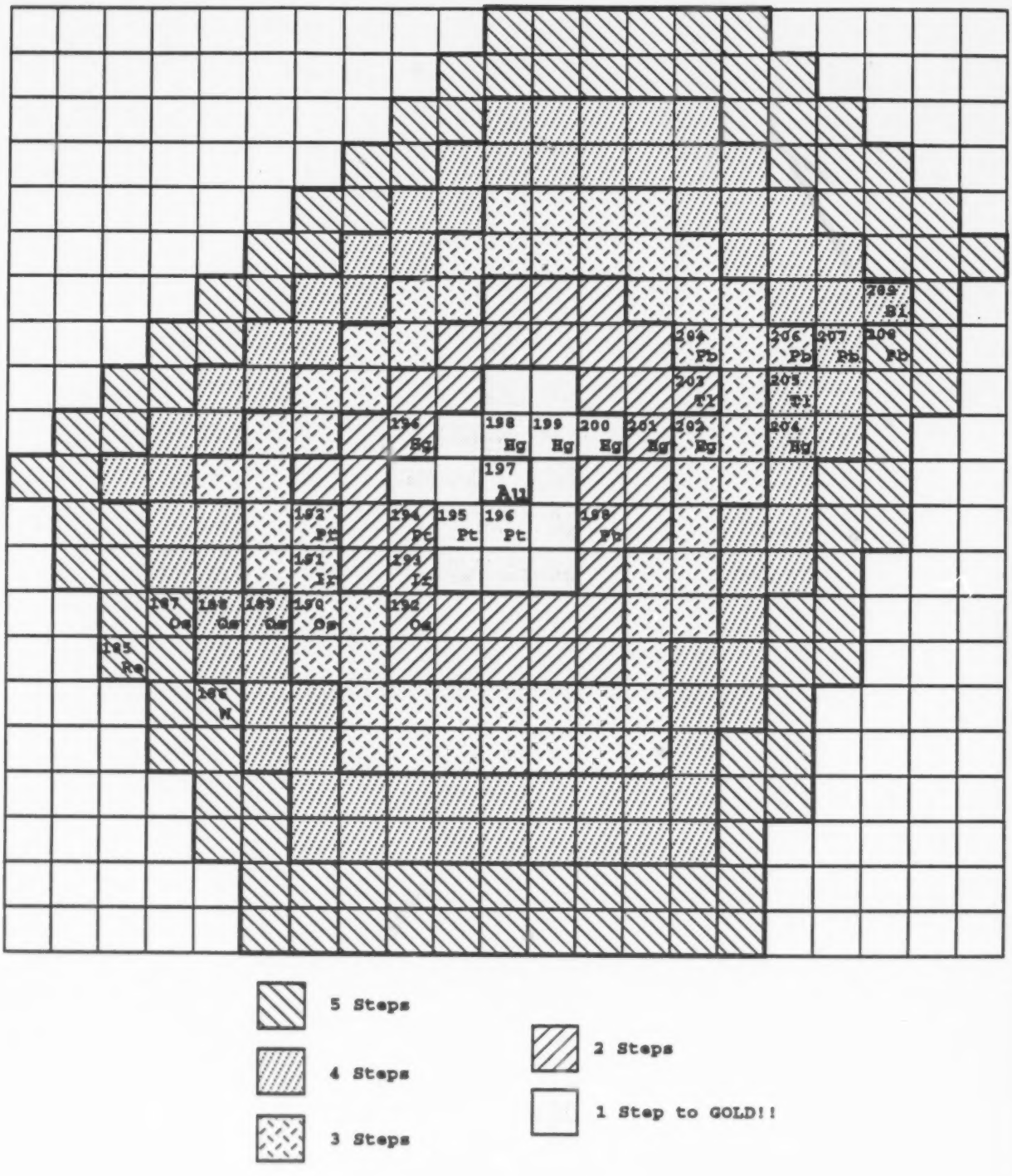


Figure 1

```
1010 '                    GOLD
1020 '
1030 REM THIS PROGRAM IS DESIGNED TO AID IN THE PROJECT ALCHEMY 161
1035 '
1036 DIM N(15),F$(15,3),T$(15,3)
1040 '
1050 REM READ DATA FOR PROCESSES INTO MEMORY
1060    DATA 2,n,3,n,pd
1070    DATA 2,n,a,n,n3
1080    DATA 2,n,p,t,3
1090    DATA 3,n,d,g,p,n,np
1100    DATA 3,n,t,g,np,n,nd
1110 '
1120    DATA 1,p,a
1130    DATA 1, t,p
1140    DATA 3,d,p,n,g,t,np
1150    DATA 3,p,np,g,n,n,2n
1160    DATA 3,a,np,t,n,3,p
1170 '
1180    DATA 3,p,g,d,n,3,np
1190    DATA 1, p,n
1200    DATA 1,a,n
1210    DATA 2,a,2n,3,n
1220    DATA 1,a,3n
1230 '
1240    FOR T = 1 TO 15
1250        READ N(T)
1260        FOR X = 1 TO N(T)
1270            READ F$(T,X),T$(T,X)
1280        NEXT X
1290    NEXT T
1300 '
1310 REM CREATE FILE
1320    OPEN "R",1,"NUC.RND",30
1330    FIELD 1, 2 AS FX$, 2 AS FZ$, 2 AS FA$,2 AS FH$
1340    FOR XX = 1 TO 5
1350        FIELD 1, 8+ 4*(XX-1) AS DD$, 2 AS FF$(XX), 2 AS FT$(XX)
1360    NEXT XX
1370 '
1380 REM READ DATA INTO FILE
1390    FOR I = 1 TO 48
1400        READ Z,A,N
1410        ON N GOTO 1500,1800,2400
1420 '
1500    REM 1-STEP ISOTOPES
1510        READ T
1520        FOR X = 1 TO N(T)
1530            A$(1)=F$(T,X)
1540            B$(1)=T$(T,X)
1550            GOSUB 4000
1560        NEXT X
1565        GOTO 3000
1570 '
1800    REM 2-STEP ISOTOPES
1810        READ T1,T2
1820        FOR X = 1 TO N(T1)
1830            A$(1) = F$(T1,X)
1840            B$(1) = T$(T1,X)
1850            FOR Y = 1 TO N(T2)
1860                A$(2) = F$(T2,Y)
1870                B$(2) = T$(T2,Y)
1880                GOSUB 4000
1890            NEXT Y
1895        NEXT X
```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```
2400     REM SUBTLE SUBSCRIPTS
2410         READ T1,T2,T3
2420         FOR X = 1 TO N(T1)
2430             A$(1) = F$(T1,X)
2440             B$(1) = T$(T1,X)
2450             FOR Y = 1 TO N(T2)
2460                 A$(2) = F$(T2,Y)
2470                 B$(2) = T$(T2,Y)
2480                 FOR W = 1 TO N(T3)
2490                     A$(3) = F$(T3,W)
2500                     B$(3) = T$(T3,W)
2510                     GOSUB 4000
2520                 NEXT W
2530             NEXT Y
2540         NEXT X
2550         GOTO 3000
2560 '
3000     NEXT I
3010     CLOSE
3020     '
3030 END
3040 '
4000 REM SUBROUTINE TO FILL FILE
4010     CT = CT + 1
4020     LSET FX$ = MKI$(CT)
4025     LSET FZ$ = MKI$(Z)
4030     LSET FA$ = MKI$(A)
4040     LSET FH$ = MKI$(N)
4050     FOR XX = 1 TO N
4060         LSET FF$(XX) = A$(XX)
4070         LSET FT$(XX) = B$(XX)
4080     NEXT XX
4090     PUT 1, CT
4100 RETURN
4110 '
8000 REM DATA
8010     DATA 80,198,1,4
8020     DATA 80,199,1,5
8030     DATA 80,200,1,6
8040     DATA 78,195,1,10
8050     DATA 78,196,1,11
8060 '
8070     DATA 80,196,2,8,3
8080     DATA 80,196,2,4,7
8090     DATA 80,196,2,3,8
8100    DATA 78,194,2,11,7
8110    DATA 78,194,2,10,6
8120    DATA 78,194,2,13,3
8130    DATA 78,194,2,3,13
8140    DATA 80,201,2,6,9
8150    DATA 78,198,2,9,12
8160    DATA 78,198,2,12,9
8170    DATA 78,198,2,5,15
8180    DATA 78,198,2,6,14
8190    DATA 77,193,2,8,13
8200    DATA 77,193,2,7,14
8210    DATA 76,192,2,10,13
8220    '
8230    DATA 80,202,3,15,6,2
8240    DATA 80,202,3,5,6,12
8250    DATA 80,202,3,6,9,9
8260    DATA 80,202,3,6,15,2
8270    DATA 80,202,3,6,5,12
```

```
1000 '                    WRTGOLD
1010 '
1020 '
1030 REM THIS PROGRAM IS DESIGNED TO PRINT THE FILE IN GOOD FORM
1035 '
1036 DIM S$(13),Z(13),A(13)
1037 '
1038 REM SET PRINTER CONTROLS
1039    GOSUB 6500
1040 '
1046 REM READ IN ELEMENTS
1047    DATA W,Re,Os,Ir,Pt,Au,Hg,Tl,Pb,Bi
1048    FOR X = 1 TO 10: READ E$(X):NEXT X
1049 '
1050 REM READ IN VALUES
1060    DATA n,0,1,      3,2,3,          pd,2,3
1070    DATA a,2,4,      n3,2,4,         p,1,1
1080    DATA t,1,3,      d,1,2,          g,0,0
1090    DATA np,1,2,     nd,1,3,         2n,0,2
1095    DATA 3n,0,3
1100 '
1110    FOR X = 1 TO 13
1120        READ S$(X),Z(X),A(X)
1122        IF LEN(S$(X))=1 THEN S$(X)=S$(X)+" "
1130    NEXT X
1140 '
1300 '
1310 REM CREATE FILE
1320    OPEN "R",1,"NUC.RND",30
1330    FIELD 1, 2 AS FX$, 2 AS FZ$, 2 AS FA$,2 AS FH$
1340    FOR XX = 1 TO 5
1350        FIELD 1, 8+ 4*(XX-1) AS DD$, 2 AS FF$(XX), 2 AS FT$(XX)
1360    NEXT XX
1380    NR = LOF(1)/30
1390 '
1400 REM READ AND PRINT
1405    LPRINT:LPRINT:LS=3
1410    FOR X = 1 TO NR
1420        GET 1,X
1430        Z = CVI(FZ$)
1440        A = CVI(FA$)
1450        N = CVI(FH$)
1452        IF LS<59 AND LS+(N*3)+3<62 THEN 1460
1455        LPRINT CHR$(12);
1456        LPRINT :LPRINT : LS=3
1460        FOR Y = 1 TO N
1470            F$ = FF$(Y)
1480            T$ = FT$(Y)
1490            C =0:B=0
1500            FOR W = 1 TO 13
1510                IF F$= S$(W) THEN C = W
1520                IF T$ = S$(W) THEN B = W
1530            NEXT W
1540            GOSUB 7000
1620        NEXT Y
1625        LPRINT:LPRINT:LPRINT:LS = LS +3
1680    NEXT X
1690 '
1700 END
```

```
6500 REM ROUTINE TO SET PRINT MODE
6503    LPRINT CHR$(27)+CHR$(67)+CHR$(66);
6505    LPRINT CHR$(27)+CHR$(97)+CHR$(0);          :'TERMINATES WP MODE
6510    LPRINT CHR$(27)+CHR$(120)+CHR$(1);         :'SETS TO LQ MODE
6520    LPRINT CHR$(27)+CHR$(107)+CHR$(3);         :'SETS TO PRESTIGE FONT
6530    LPRINT CHR$(27)+CHR$(103);                 :'SETS TO MICRON
6550 RETURN
6560 '
7000 REM GOSUB TO PRINT AN EQUATION
7002    LS = LS+3
7004    LPRINT:LPRINT:LPRINT
7005    LPRINT CHR$(14);                  :'  SETS TO DOUBLE WIDTH
7010    IF Y>1 THEN 7030
7015    CT = CT +1
7020    LPRINT USING " ###.";CT,
7030    LPRINT TAB(10);
7040    '
7050    REM PRINT FIRST NUCLIDE
7060        S$ = E$(Z-73)
7070        TP=A:BT=Z
7080        GOSUB 8000
7090        LPRINT " + ";
7100    '
7110    REM PRINT INCIDENT PARTICLE
7115        FL = 0
7120        PN=C: GOSUB 8500
7125        IF FL = 0 THEN LPRINT TAB(38); ELSE LPRINT TAB(31);:FL=0
7130        LPRINT  "--> ";
7140    '
7150    REM PRINT NEW NUCLIDE
7155        Z = Z + Z(C) - Z(B)
7156        A = A + A(C) - A(B)
7160        S$ = E$(Z-73)
7170        TP=A:BT=Z
7180        GOSUB 8000
7190        LPRINT " + ";
7200    '
7210    REM PRINT RESULTING PARTICLE
7220        PN = B:GOSUB 8500
7230    '
7240 RETURN
7250 '
8000 REM GOSUB TO PRINT A SINGLE NUCLIDE OR PARTICLE
8010    LPRINT CHR$(27)+CHR$(106)+CHR$(10);     :' LINE FEED UP
8020    LPRINT CHR$(27)+CHR$(83)+CHR$(0);       :' SET TO SUPERSCRIPT
8030    LPRINT USING "###";TP,
8040    LPRINT CHR$(27) + CHR$(84);
8043    LPRINT CHR$(27)+ CHR$(74)+CHR$(20);      :'LINEFEED DOWN
8050    LPRINT  CHR$(8);CHR$(8);CHR$(8);         :'BACKSPACE 3
8060    LPRINT CHR$(27)+CHR$(83)+CHR$(1);        :'SET TO SUBSCRIPT
8070    LPRINT USING "###";BT,
8080    LPRINT CHR$(27)+CHR$(84);                :'RELEASE
8085    LPRINT CHR$(27)+CHR$(106)+CHR$(10);     :' LINE FEED UP
8090    LPRINT USING "\\";S$,
8100 RETURN
```

```
8500 REM GOSUB TO CONTROL PRINTING OF PARTICLES
8502    IF PN >11 THEN 8510
8505    FOR L = 1 TO 2:LPRINT CHR$(6),:NEXT L
8510    ON PN GOTO 8550,8600,8650,8700,8750,8800,8850,8900,8950,9000,9050,9100,9
150
8520    '
8550    REM n
8560    TP=1:BT=0:S$="n"
8570    GOSUB 8000:GOTO 9200
8580    '
8600    REM 3
8610    TP=3:BT=2:S$="He"
8620    GOSUB 8000:GOTO 9200
8630    '
8650    REM pd
8660    TP = 1:BT=1:S$="H":GOSUB 8000
8670    LPRINT " + ";
8675    FOR L = 1 TO 2:LPRINT CHR$(8);:NEXT L
8680    TP = 2:BT=1:S$ ="H":GOSUB 8000:GOTO 9200
8690    '
8700    REM a
8710    TP = 4:BT=2:S$="He":GOSUB 8000:GOTO 9200
8720    '
8750    REM n3
8760    TP = 1:BT=0:S$="n":GOSUB 8000
8770    LPRINT " + ";
8775    FOR L = 1 TO 2:LPRINT CHR$(8);:NEXT L
8780    TP = 3:BT= 2:S$="He":GOSUB 8000:GOTO 9200
8790    '
8800    REM p
8810    TP = 1:BT = 1:S$="H":GOSUB 8000:GOTO 9200
8820    '
8850    REM t
8860    TP = 3:BT=1:S$="H":GOSUB 8000:GOTO 9200
8870    '
8900    REM d
8910    TP = 2:BT=1:S$="H":GOSUB 8000:GOTO 9200
8920    '
8950    REM G
8955    FL=1
8960    LPRINT " ";:GOTO 9200
8970    '
9000    REM np
9010    TP = 1:BT = 0: S$="n":GOSUB 8000
9020    LPRINT " + ";
9025    FOR L = 1 TO 2:LPRINT CHR$(6);:NEXT L
9030    TP = 1:BT = 1: S$="H" : GOSUB 8000:GOTO 9200
9040    '
9050    REM nd
9060    TP = 1:BT = 0: S$="n":GOSUB 8000
9070    LPRINT " + ";
9075    FOR L = 1 TO 2:LPRINT CHR$(8);:NEXT L
9080    TP = 2:BT = 1: S$="H" : GOSUB 8000:GOTO 9200
9090    '
9100    REM 2n
9110    LPRINT "2 ";
9120    FOR L = 1 TO 2:LPRINT CHR$(8);:NEXT L
9130    TP = 1:BT = 0: S$="n":GOSUB 8000:GOTO 9200
9140    '
9150    REM 3n
9160    LPRINT "3 ";
9165    FOR L = 1 TO 2:LPRINT CHR$(8),:NEXT L
9170    TP = 1:BT = 0: S$="n":GOSUB 8000:GOTO 9200
9180    '
9200    END
```

77

Name: _____

LET'S MAKE GOLD

Balance the following nuclear reactions by placing the correct symbol, atomic number and atomic mass in the rectangular box.

1. $\square + {}^{1}_{0}n \rightarrow {}^{195}_{79}Au + {}^{1}_{0}n + {}^{1}_{1}H$

   ${}^{195}_{79}Au + \square \rightarrow {}^{197}_{79}Au + {}^{1}_{1}H$

2. ${}^{192}_{78}Pt + \square \rightarrow {}^{193}_{78}Pt + {}^{1}_{0}n + {}^{1}_{1}H$

   $\square + {}^{3}_{1}H \rightarrow {}^{195}_{79}Au + {}^{1}_{0}n$

   ${}^{195}_{79}Au + {}^{3}_{1}H \rightarrow {}^{197}_{79}Au + \square$

3. ${}^{191}_{77}Ir + {}^{4}_{2}He \rightarrow \square + {}^{1}_{0}n + {}^{1}_{1}H$

   ${}^{191}_{77}Ir + {}^{4}_{2}He \rightarrow \square + {}^{1}_{0}n + {}^{1}_{1}H$

   ${}^{191}_{77}Ir + {}^{3}_{1}H \rightarrow {}^{193}_{77}Ir + \square$

4. ${}^{192}_{78}Pt + \square \rightarrow {}^{194}_{79}Au + {}^{1}_{0}n + {}^{1}_{1}H$

   ${}^{194}_{79}Au + {}^{3}_{1}H \rightarrow {}^{196}_{79}Au + \square$

   ${}^{196}_{79}Au + {}^{2}_{1}H \rightarrow {}^{197}_{79}Au + \square$

5. $^{192}_{78}Pt + {}^{4}_{2}He \rightarrow$ ☐ $+ {}^{1}_{0}n$

$^{192}_{78}Pt +$ ☐ $\rightarrow {}^{192}_{77}Ir + {}^{3}_{2}He$

$^{192}_{77}Ir +$ ☐ $\rightarrow {}^{194}_{77}Ir + {}^{1}_{1}H$

6. ☐ $+ {}^{2}_{1}H \rightarrow {}^{197}_{80}Hg + {}^{1}_{1}H$

$^{197}_{80}Hg + {}^{1}_{0}n \rightarrow$ ☐ $+ {}^{1}_{1}H$

7. $^{203}_{81}Tl + {}^{1}_{1}H \rightarrow$ ☐ $+ {}^{1}_{0}n$

$^{203}_{81}Tl +$ ☐ $\rightarrow {}^{200}_{80}Hg + {}^{4}_{2}He$

☐ $+ {}^{1}_{0}n \rightarrow {}^{197}_{78}Pt + {}^{4}_{2}He$

8. $^{202}_{80}Hg + {}^{1}_{1}H \rightarrow {}^{199}_{79}Au +$ ☐

$^{199}_{79}Au + {}^{4}_{2}He \rightarrow$ ☐ $+ 3\ {}^{1}_{0}n$

$^{199}_{79}Au + {}^{1}_{0}n \rightarrow$ ☐ $+ {}^{1}_{0}n + {}^{3}_{2}He$

8.1

Name: _____

GOLD AT THE END OF THE RAINBOW

Write the following nuclear reactions in equation form.

Symbols: n - neutron p - proton t - triton γ - gamma
h - helium-3 α - alpha d - deuteron

Example: $^{196}_{80}Hg$ (n, p), (t, np)

$$^{196}_{80}Hg + ^{1}_{0}n \rightarrow ^{196}_{79}Au + ^{1}_{1}H$$

$$^{196}_{79}Au + ^{3}_{1}H \rightarrow ^{197}_{79}Au + ^{1}_{0}n + ^{1}_{1}H$$

1. $^{199}_{80}Hg$ (n, t)

2. $^{192}_{76}Os$ (t, n), (α, n)

3. $^{202}_{80}Hg$ (p, α), (n, nd), (p, n)

4. $^{191}_{77}Ir$ (h, p), (h, p), (t, p)

5. $^{192}_{78}Pt$ (t, n), (d, p), (t, p)

80

6. $^{192}_{78}Pt$ (h, p), (d, p), (t, p)

7. $^{204}_{82}Pb$ (p, np), (p, α), (n, α)

8. $^{192}_{78}Pt$ (h, p), (t, p), (t, np)

9. $^{202}_{80}Hg$ (p, α), (γ, n), (p, np)

10. $^{191}_{77}Ir$ (t, n), (h, p), (t, p)

Gold Dig

a card game

Objective: to become familiar with the Chart of the Nuclides and the table of "Displacements Caused by Nuclear Bombardment Reactions".

Materials: Set of 17 different nuclide cards
Six sets of 13 different particle cards showing bombarding particle first, then particle or particles ejected
Chart of the stable nuclides within three steps of Gold-197 (See previous Fig 1)
Reference list of 179 sets of equations for making gold (WRTGOLD program)
Table of "Displacements Caused by Nuclear Bombardment Reactions"

Directions:

1. Up to five students may play.

2. Separate the nuclide cards into three packs. The first pack should contain only those nuclides that need one step to become Gold-197. These cards have a number one on them. The second pack should contain only those nuclides needing two steps to become Gold-197; they have a number two on them. Finally, the third pack consists of the remaining nuclides that require three steps; they contain a number three.

3. Dealer deals each player one nuclide card from each pack. Then the nuclide packs are put aside and are not used during the rest of this particular game.

4. Dealer shuffles and deals the particle cards so that each player receives twelve of them. The remaining particle cards are placed face down in a pile in the middle of the table.

5. Player to left of the dealer begins. Player consults hand and reference list of 179 equations, and puts down, if possible, one nuclide card plus the correct particle cards needed to make Gold-197. For example , if the player has the nuclide Ir-191, it may be laid down if player also has:

alpha, neutron	α, n
triton, proton	t, p
triton, neutron/proton	t, np

Other combinations of particle cards are also valid for Ir-191. The combination must be verified in the list of 179 ways to make gold. For the example above, equation set number 155 shows this procedure for making gold.

6. Whether or not the player is able to lay down a nuclide card and its correct particle cards, player may either:

pick up the top card from the pile of particle cards, and discard a different particle card face up on a discard pile

or

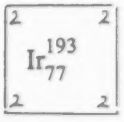
pick up the top card from the discard pile and put a different particle card down on the discard pile.

7. Game ends when a player has put down all of his/her particle and nuclide cards.

Making the Nuclide Cards:

On two sheets of 8 1/2 " by 11 " paper (colored if possible) rule off nine rectangles 2 1/2 " by 3 " each. Write one of the following nuclides in each of the seventeen boxes. Put the number corresponding to the number of steps needed for that nuclide to be transformed to gold in each of the four corners of the box. See examples below.

and



Nuclides requiring only one step: Hg_{80}^{200} , Hg_{80}^{199} , Hg_{80}^{198} , Pt_{78}^{195} , Pt_{78}^{196}

Nuclides requiring two steps: Hg_{80}^{196} , Hg_{80}^{201} , Os_{76}^{192} , Ir_{77}^{193} , Pt_{78}^{194} , Pt_{78}^{198}

Nuclides requiring three steps: Hg_{80}^{202} , Os_{76}^{190} , Ir_{77}^{191} , Pt_{78}^{192} , Pb_{82}^{204} , and Tl_{81}^{203}

Cut out the seventeen cards and discard the one unused one.

Making the Particle Cards:

On a sheet of white 8 1/2 " by 11 " paper rule off nine rectangles 2 1/2 " by 3 " each. Make eight copies of this sheet. In six of the rectangles write the symbol for an alpha particle, α , being sure to underline it so that it will not be confused with a gamma, γ. In another six boxes write a p for proton and underline it so it will not be mistaken for a d. Continue similarly with d (deuteron), pd (proton and deuteron), np (neutron and proton), nd (neutron and deuteron), t (triton), γ (gamma), He_2^3, nHe_2^3, n, 2n, and 3n. There will then be 78 particle cards, six each of the thirteen kinds. Cut out the 78 cards and discard the three unused ones.

83

Captain Nuclide

by Michael J. Polashenski

Introduction:

This card game may be played by up to five persons per game, all of whom may use the Chart of the Nuclides at any time. The game is designed to familiarize the players with the use of the Chart of the Nuclides. The Chart arranges nuclides according to both their number of neutrons and their number of protons. All atoms tend toward stability. Those colored gray on the Chart already are stable and will not decay. All other atoms are radioactive and will approach the "line of stability" by various methods. Some common methods used in this game are listed below:

α	alpha (helium nucleus) emission
β^-	negative beta (electron or negatron) decay
β^+	positive beta (positron) decay
γ	gamma (photon or electromagnetic radiation) emission
ε	electron capture
IT	isomeric transition

The goal of the game is to obtain as many tricks representing natural decays and emissions as possible.

Materials:

Chart of the Nuclides (Appendix B, Info. Sources #1)
Deck of 86 Nuclide Cards
Deck of 56 Transmutation Cards
One die
Pencil or pen
Paper

Play of the Game:

1. Shuffle the decks of cards separately. Roll die to determine the dealer. Each player is dealt ten transmutation cards. (Transmutation is the changing of one element to another. Gamma emissions and isomeric transitions can be part of a decay chain but cannot themselves cause a mutation.) The nuclide deck is placed in the center with the top card face up.

2. Find this nuclide on the Chart of the Nuclides. If it is already stable, place it to the side of the deck and turn the next card face up. (The stable nuclides may be used later by any /all player(s) to complete a natural radioactive decay chain.) Otherwise, the player with the greatest number of natural decays and emissions for the nuclide places those transmutation cards (only one of each, please) on top of the nuclide card. (If no player can form a trick with the upturned nuclide card, it is removed and the next nuclide card is turned up.) At this point the nuclide has decayed . (See step 5 in case of ties.)

3. The player must then correctly name the daughter products in order to take the trick, consisting of the nuclide card and its relevant transmutation cards. If the player makes an error or cannot name a daughter product, the next player to the left attempts to name the daughter products correctly to take the trick. Attempts at correct naming of daughter products continue to the left until the trick is taken. (Players to the left cannot place additional transmutation cards on the trick.)

4. After the trick is taken, the next nuclide card is turned face up and steps two and three are repeated. The play of the hand ends when any player runs out of transmutation cards.

5. In the case of two or more players creating a tie for the greatest number of applicable transmutation cards, a die is rolled by each player. High roller wins the tie and places down the transmutation cards.

6. To begin a new hand, first score the old hand, then collect, reshuffle and redeal the transmutation cards only and turn up the next nuclide card. Each player retains his/her nuclides from tricks won so they may be used in forming natural decay chains at the end of the game.

7. The game ends after a predetermined number of hands, or length of time, or point level, but the hand in progress must be completed to end the game.

Scoring:

1. At the end of a hand, each player sums the atomic mass numbers of his/her nuclides from tricks won.

2. Each player then subtracts 100 points for each unused transmutation card remaining in his/her hand. Record each player's point total for the hand. (Negative scores are quite probable for the players who did not take the trick.)

3. At the end of the game, each player attempts to make one or more complete natural radioactive decay chains using the nuclides won plus any of the stable nuclide cards. Nuclides won may be used in only one decay chain; stable nuclide cards turned over at the start of a hand may be used by any and all players in any number of decay chains. Each complete decay chain is worth 1000 bonus points.

4. Add all the hand point totals and bonus point totals for the score.

5. The player with the highest score wins and earns the title Captain Nuclide until dethroned by another player in another game, or until decaying back to Private Nuclide, whichever comes first. The radioactive half life for the title of Captain Nuclide is twelve hours.

Making the Nuclide Cards:

On a piece of 8 1/2 " by 11 " colored paper rule off 20 boxes, each 2 " by 2 ". Make four additional copies of this grid on same color paper. In the boxes print the chemical symbol and mass number of one of the nuclides listed on the following pages, placing a different nuclide in each box. The eighty-four cards are used by one group of up to five players, so copy the sheets of cards at this point as many times as needed before cutting the cards apart.

Element	Symbol and Mass Number
actinium	Ac-225, Ac-227, Ac-228
americium	Am-241
astatine	At-215, At-217, At-218
barium	Ba-137m
beryllium	Be-7
bismuth	Bi-209, Bi-210, Bi-211, Bi-212, Bi-213, Bi-214
cadmium	Cd-113, Cd-113m
carbon	C-14
cesium	Cs-137
cobalt	Co-60
francium	Fr-221, Fr-223
hydrogen	H-3
indium	In-115m, In-115, In-116m
iodine	I-125
lead	Pb-206, Pb-207, Pb-208, Pb-209, Pb-210, Pb-211, Pb-212, Pb-214
neptunium	Np-237
plutonium	Pu-241
polonium	Po-211, Po-212, Po-213, Po-214, Po-215, Po-216, Po-218
potassium	K-40
protactinium	Pa-231, Pa-233, Pa-234m, Pa-234
radium	Ra-223, Ra-224, Ra-225, Ra-226, Ra-228
radon	Rn-219, Rn-220, Rn-222
rubidium	Rb-87
silver	Ag-108, Ag-110
sodium	Na-22, Na-24

strontium	Sr-90
tellurium	Te-123, Te-123m
thallium	Tl-206, Tl-207, Tl-208, Tl-209, Tl-210
thorium	Th-227, Th-228, Th-229, Th-230, Th-231, Th-232, Th-234
uranium	U-233, U-234, U-235, U-237, U-238
vanadium	V-50
zinc	Zn-65

Making Transmutation Cards:

On a piece of plain white 8 1/2 " by 11 " paper rule off 20 boxes, each 2 " by 2 ". Make two additional copies. Write the following transmutations in the boxes as noted:

α emission - put in 8 boxes

γ emission - put in 8 boxes

β^+ decay - put in 8 boxes

β^- decay - put in 8 boxes

ϵ capture - put in 8 boxes

IT - put in 8 boxes

Be sure to write the word "emission" beneath the alpha and gamma symbols to prevent confusion in reading the correct symbol when a card is turned on its side.

One set of these 56 transmutation cards is required for each group of players, so make the appropriate number of copies of these sheets before cutting the 56 cards apart.

Flip Book Chart of the Nuclides:
The Uranium-238 Decay Chain

by Michael Szesze

Students often have difficulty in "seeing the forest for the trees" when examining the Chart of the Nuclides (See Appendix B, Information Sources #1) because so much information is given in each cell of the chart. In tracing the natural decay chain of uranium-238 to lead-206 the presence of so many other nuclides tends to hide the stepwise nature of the decay. The Flip Book Chart of the Nuclides helps students to visualize more clearly exactly what occurs by omitting the information on all nuclides except those involved in the decay. As the flip book pages flash by from front to back one sees in bold print consecutive individual steps in the decay series and also the previous steps in lighter print. On the last page the entire decay series is shown. Students may use the flip book over and over to gain a quick overall view of the decay series or may study each step individually in the series.

At the end of the flip chart are instructions for assembling the flip book, a key to the symbols used, and a set of questions for review. To make sturdy copies that will survive student handling copy all the pages onto heavy paper using one side of the paper only. Then follow the directions for assembly found on the last page.

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
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Instructions for Assembling the Flip Book Chart of the Nuclides

1. Cut out all of the cards (1-45) and place them in a stack with 1 on top.
2. Tap the stack on its side so that all cards are flush with the right side.
3. Staple the left side of the flip book together with two or three staples.
4. Hold the flip book in the left hand with your thumb and finger tips.
5. Use your right thumb and fingers to leaf through the pages and see the animation.

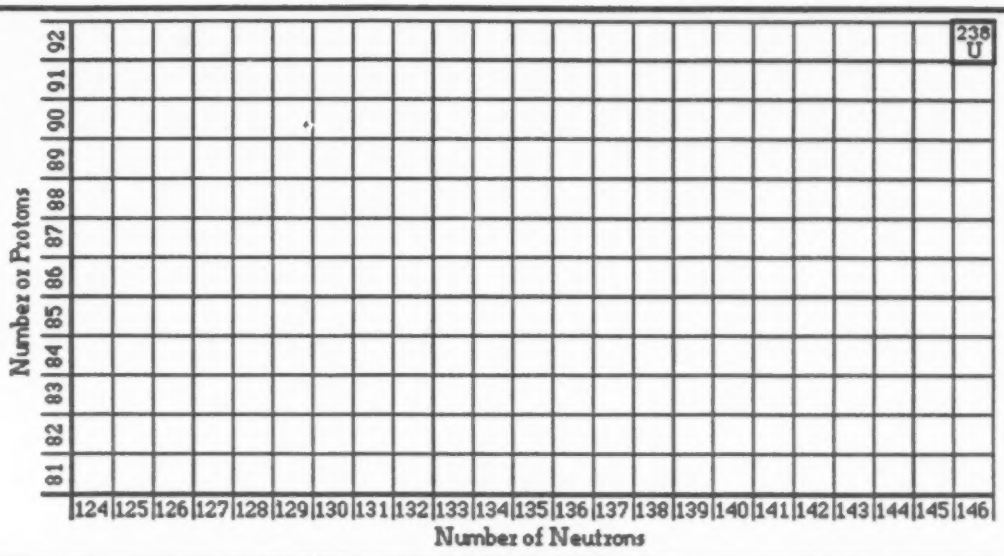
45

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Uranium-238

U238
4.47E9 y
α to Th234

Stable
Natural



1

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Alpha Decay

α out

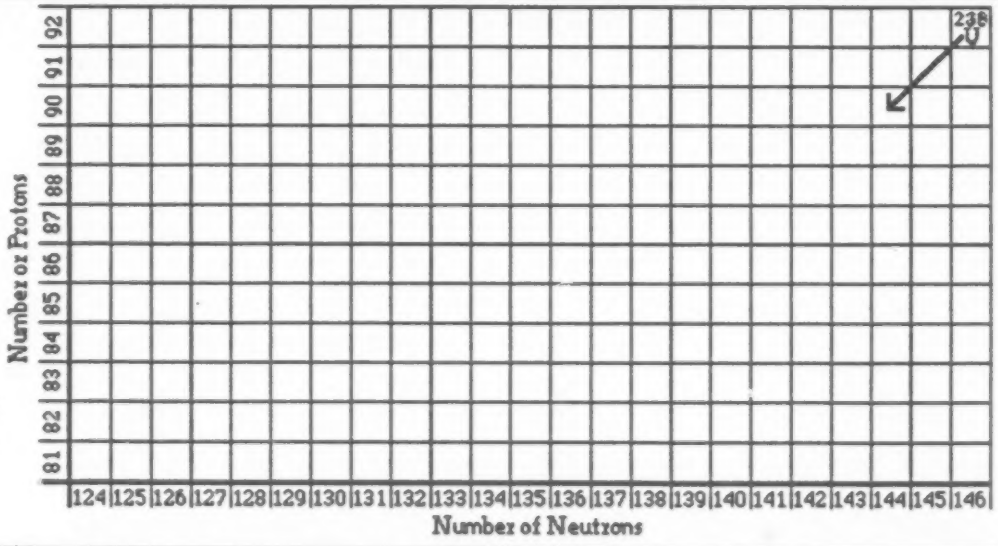
U238

α

Th234

Alpha Paticle

large, massive
2p 2n
He nucleus
high LET

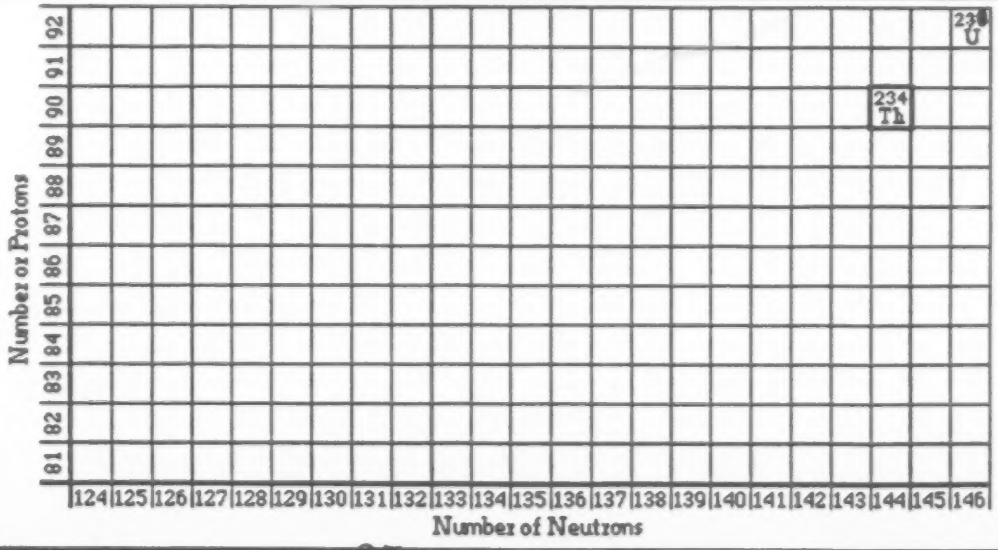


2

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Thorium-234

Th234
24.10 d
β⁻ to Pa234



3

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Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Seesze

Beta Decay

β⁻ out

Th234

β⁻

Pa234

Beta Particle

electron
small
medium LET

4

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Seesze

Protactinium-234

Pa234
1.17 m
β⁻ to U234

5

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Seesze

Beta Decay

β⁻ out

Pa234

β⁻

U234

Beta Particle

electron
small
medium LET

6

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Uranium-234

U234
2.46E7 y
α to Th230

Natural

7

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Alpha Decay

α out

U234

α

Th230

Alpha Paticle

large, massive
2p 2n
He nucleus
high LET

8

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Thorium-230

Th230
7.5E4y
β⁻ to Ra226

provides
color &
fluorescence
to glass

9

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Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Alpha Decay

α out

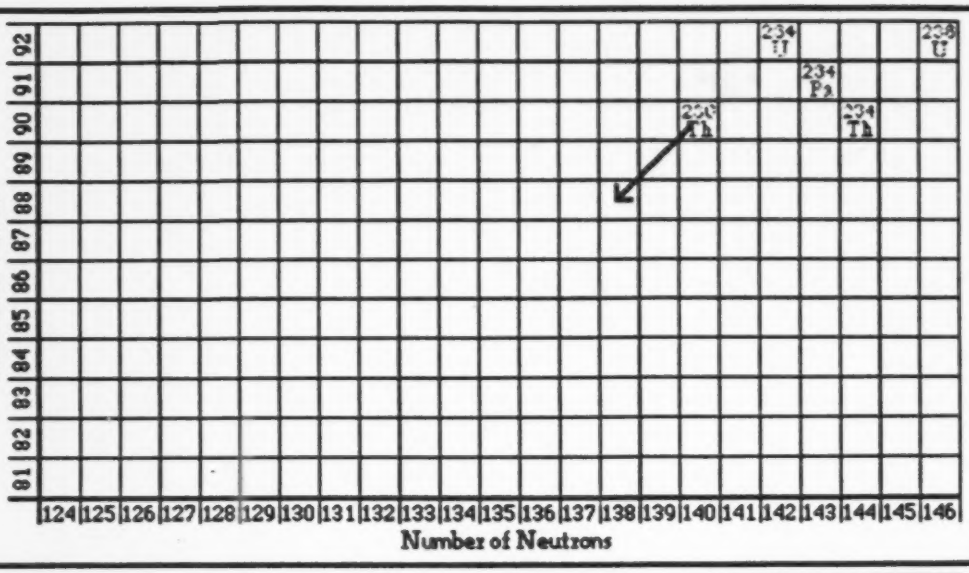
Th230

α

Ra226

Alpha Paticle

large, massive
2p 2n
He nucleus
high LET



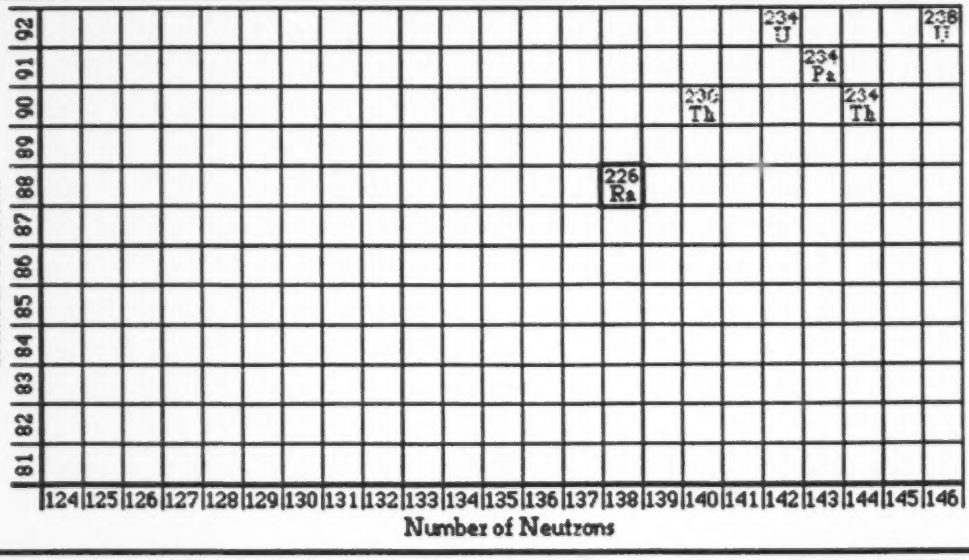
10

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Radium-226

Ra226
1.60E3 y
β⁻ to Rn222

makes
lightning rods
more effective



11

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Alpha Decay

α out

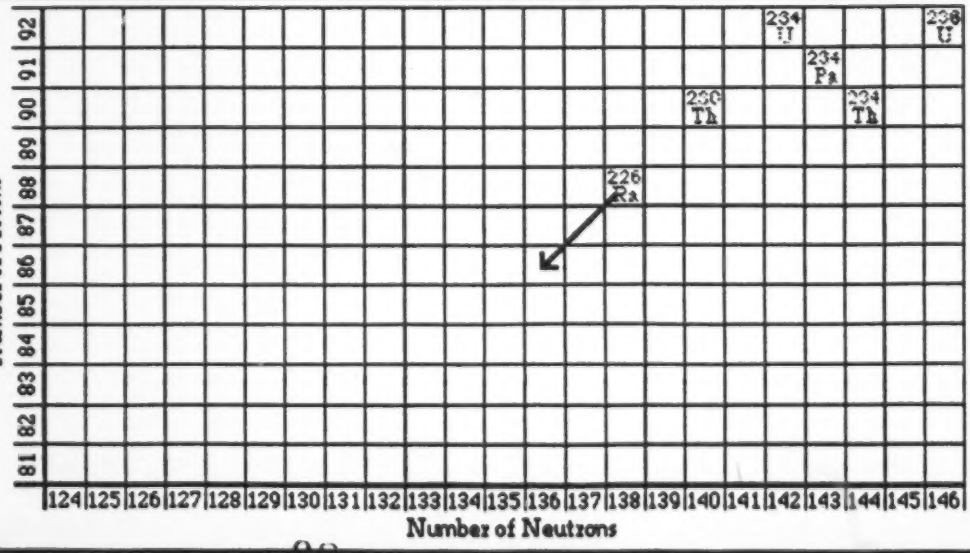
Ra226

α

Rn222

Alpha Paticle

large, massive
2p 2n
He nucleus
high LET



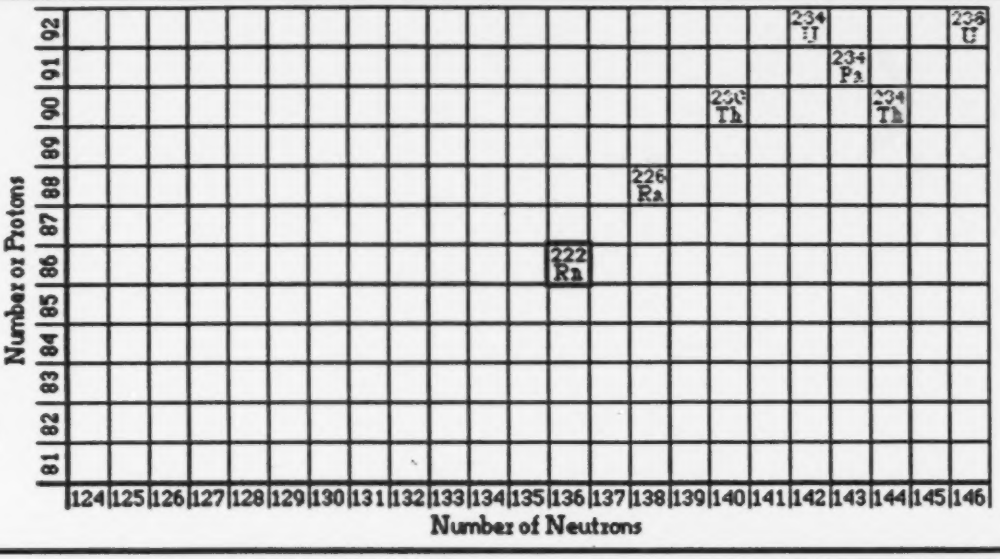
12

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Radon-222

Ra222
3.8235 d
α to Po218

Gaseous
travels readily



13

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Alpha Decay

α out

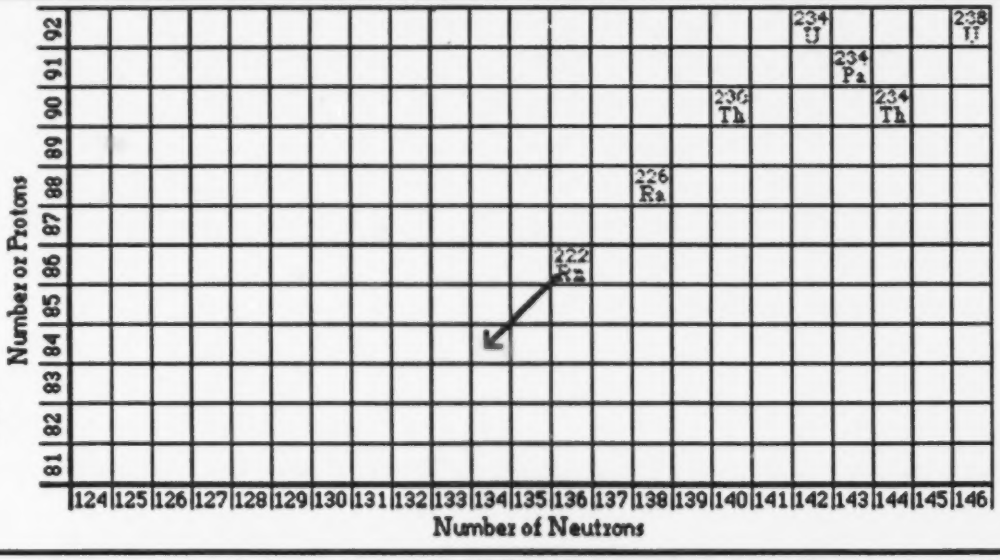
Rn 222

α

Po218

Alpha Paticle

large, massive
2p 2n
He nucleus
high LET



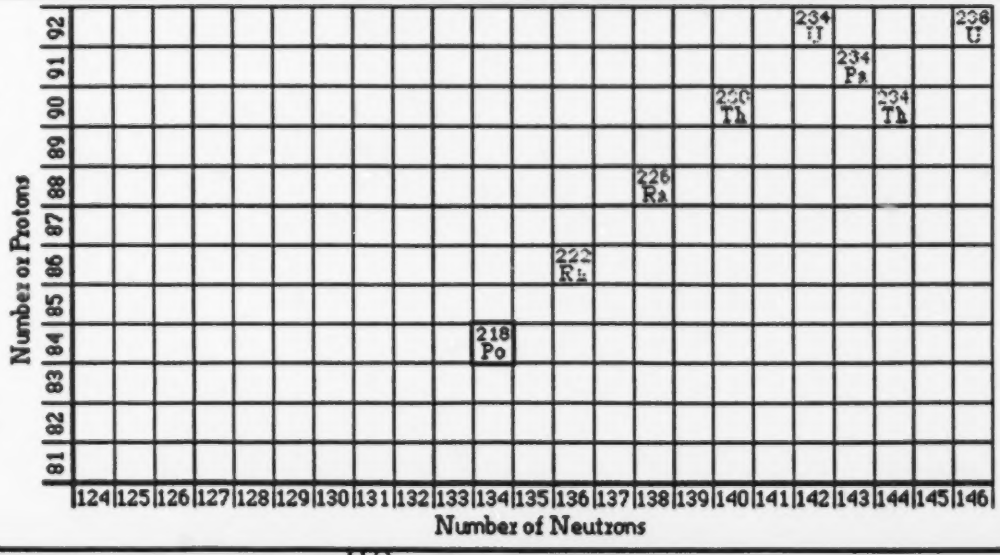
14

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Polonium-218

Po218
3.10 m
α to Pb214
β⁻ to At218

Solid
dust to lungs
causes cancer



15

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Beta Decay

β⁻ out

Po218

β⁻

At218

Beta Particle

electron
small
medium LET

16

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Astatine-218

At218
1.6 s
α to Bi214

Solid
dust to lungs
causes cancer

17

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Alpha Decay

α out

At218

α

Bi214

Alpha Paticle

large, massive
2p 2n
He nucleus
high LET

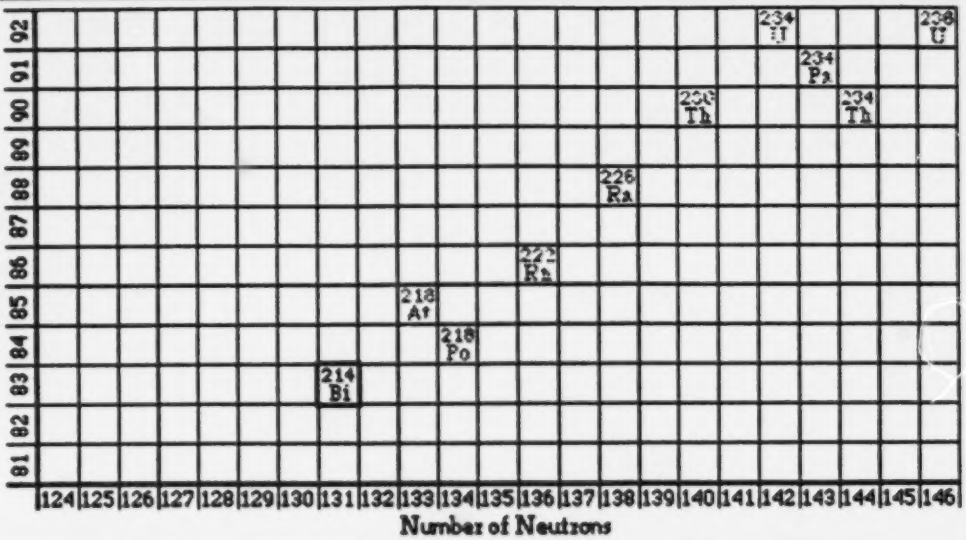
18

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Bismuth-214

Bi214
19.9 m
α to Tl210
β⁻ to Po214

Solid
dust to lungs
causes cancer



19

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Alpha Decay

α out

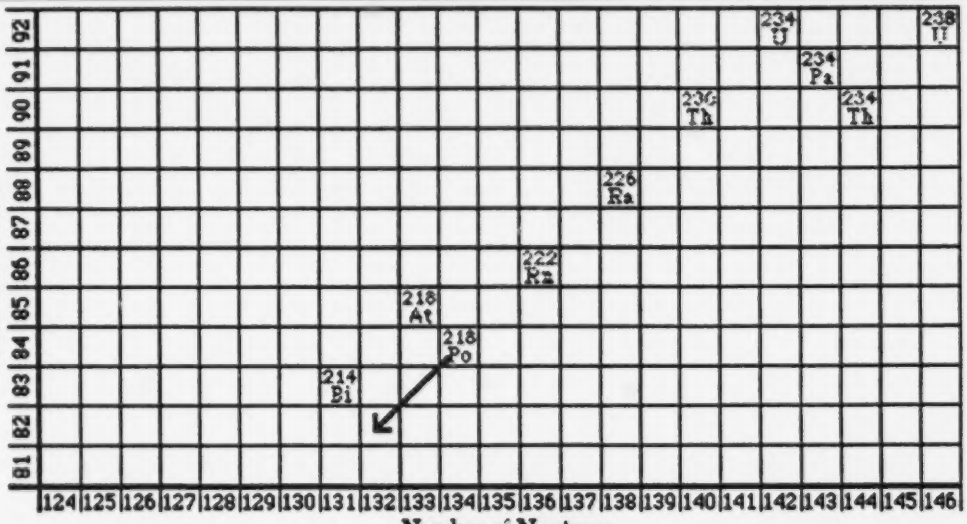
Po218

α

Pb214

Alpha Paticle

large, massive
2p 2n
He nucleus
high LET



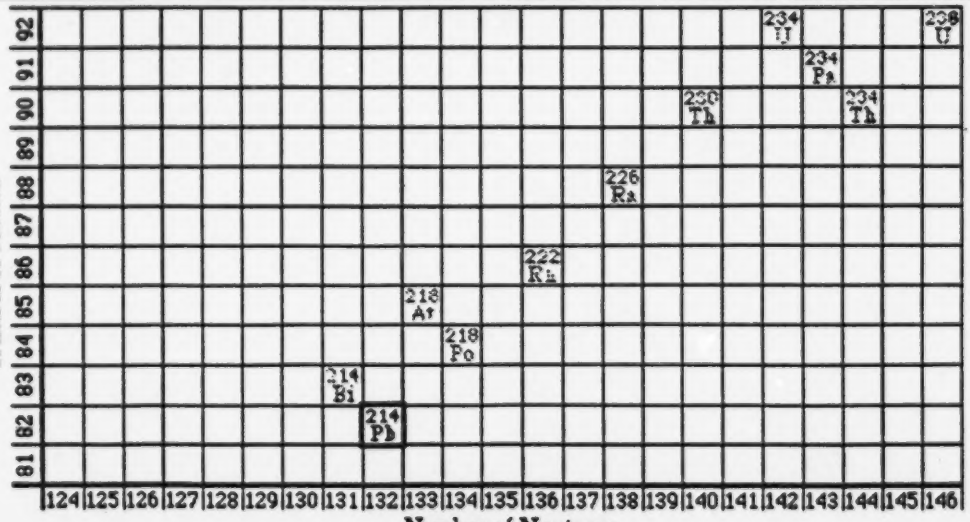
20

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Lead-214

Pb214
27 m
β⁻ to Bi214

Solid
dust to lungs
causes cancer



21

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Beta Decay

β⁻ out

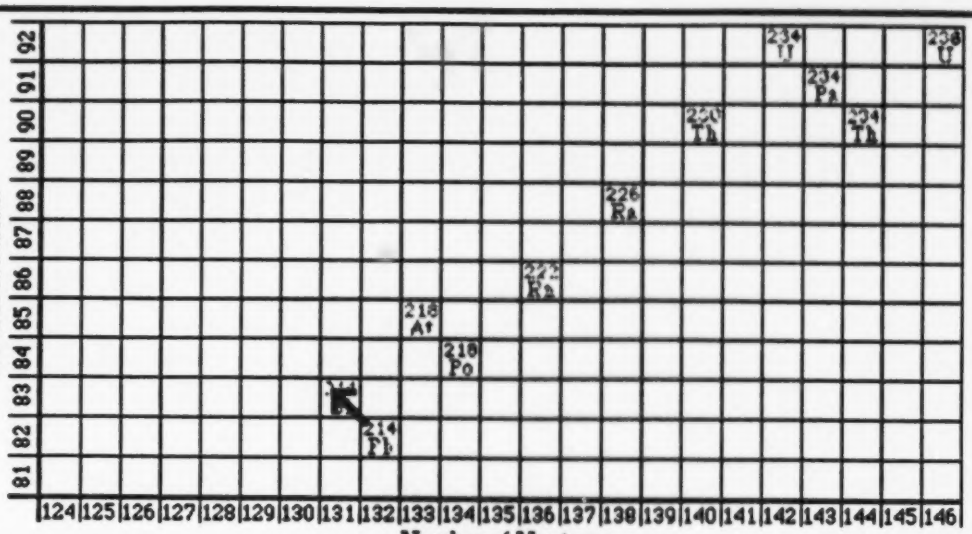
Pb214

β⁻

Bi214

Beta Particle

electron
small
medium LET



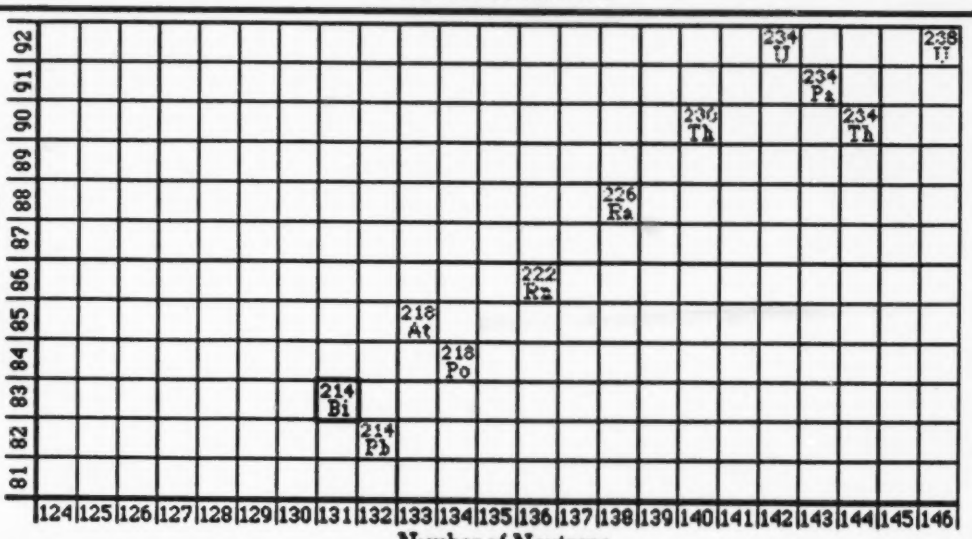
22

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Bismuth-214

Bi214
19.9 m
α to Tl210
β⁻ to Po214

Solid
dust to lungs
causes cancer



23

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Beta Decay

β⁻ out

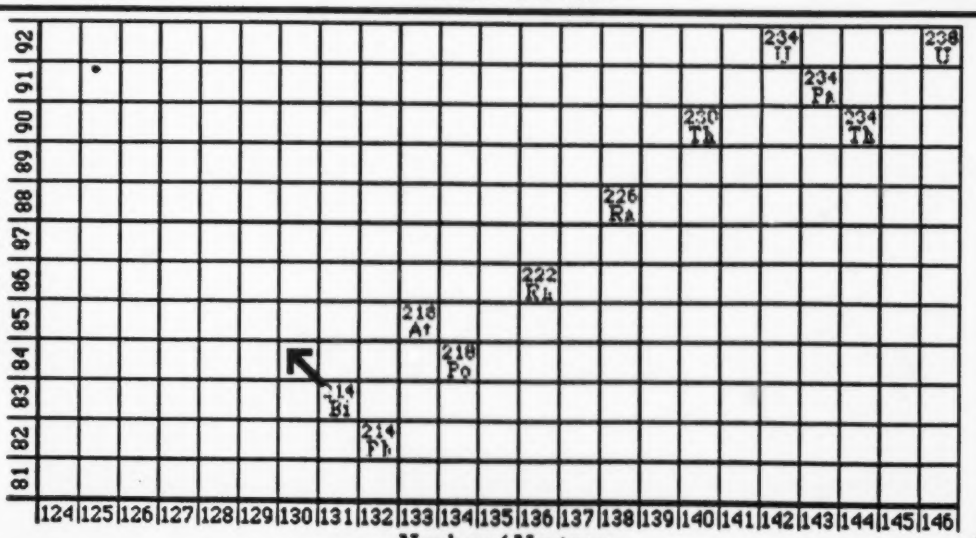
Bi214

β⁻

Po214

Beta Particle

electron
small
medium LET



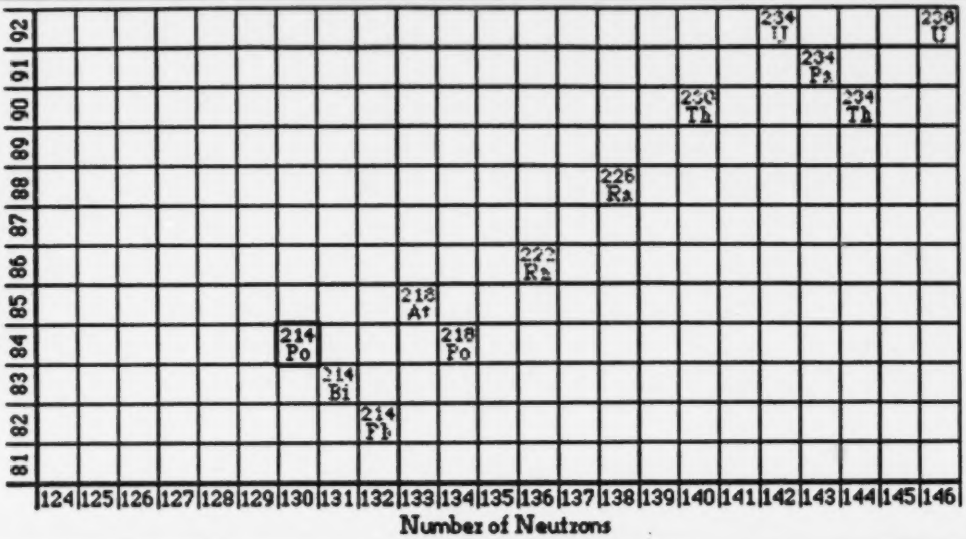
24

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Polonium-214

Po214
136.7 μs
α to Pb210

Solid
dust to lungs
causes cancer



25

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Alpha Decay

α out

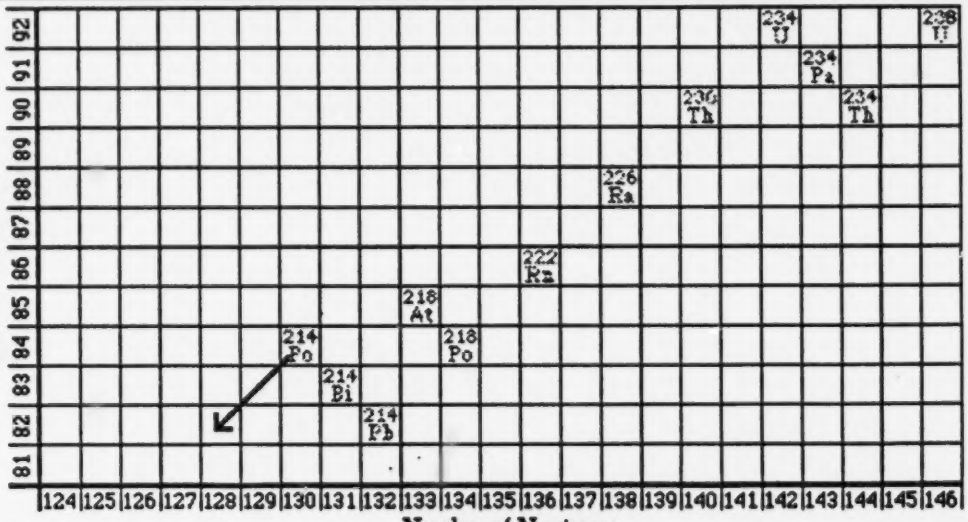
Po214

α

Pb210

Alpha Paticle

large, massive
2p 2n
He nucleus
high LET



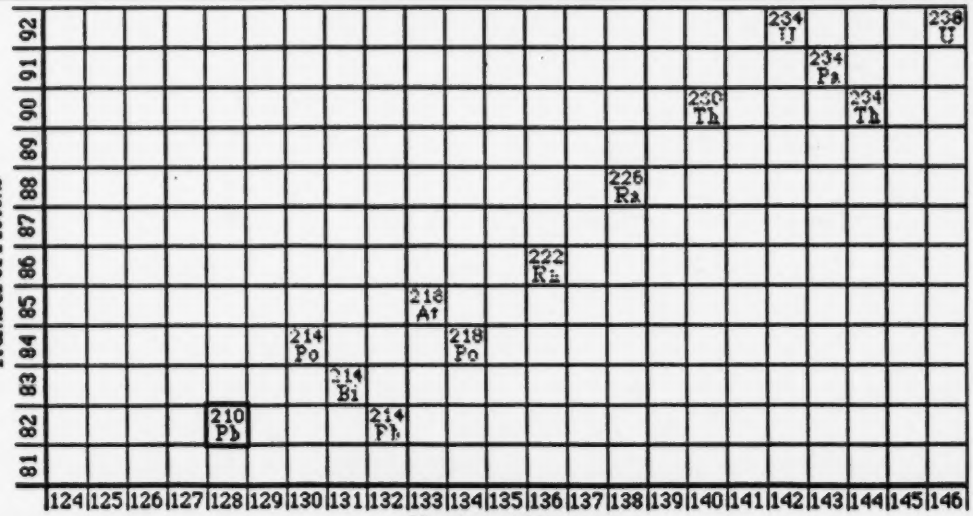
26

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Lead-210

Pb210
22.3 y
β⁻ to Bi210

Solid
dust to lungs
causes cancer



27

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Alpha Decay

α out

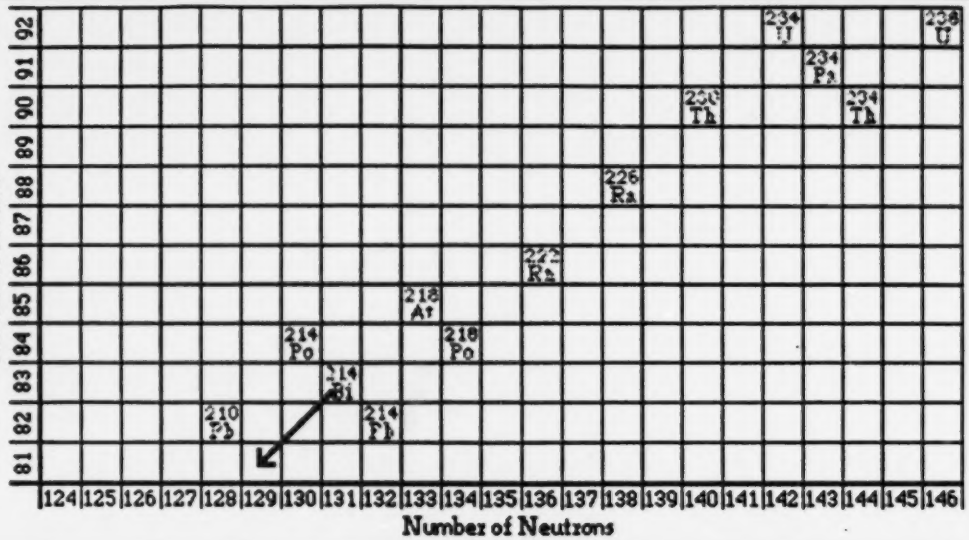
Bi214

α

Tl210

Alpha Paticle

large, massive
2p 2n
He nucleus
high LET



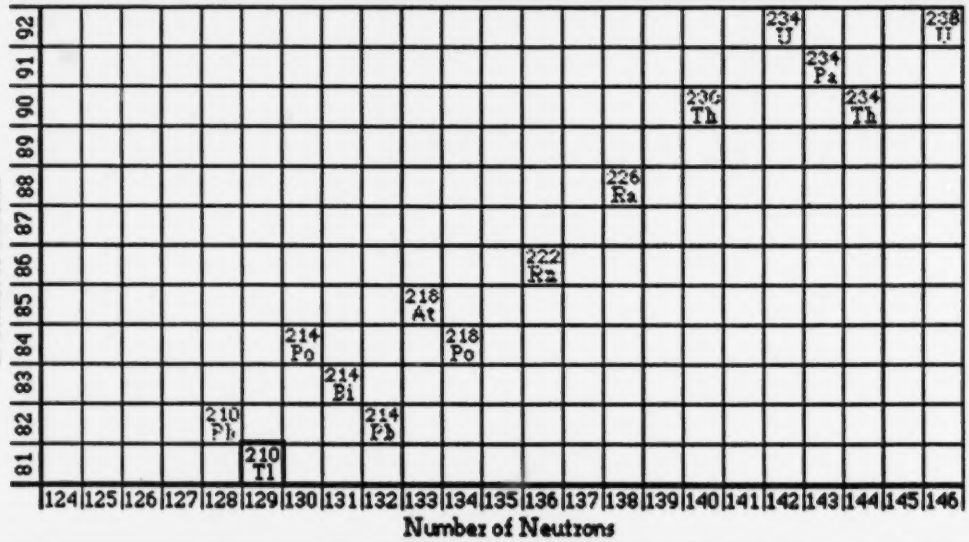
28

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Thallium-210

Tl210
1.30 s
β⁻ to Pb210

Solid
dust to lungs
causes cancer



29

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Beta Decay

β⁻ out

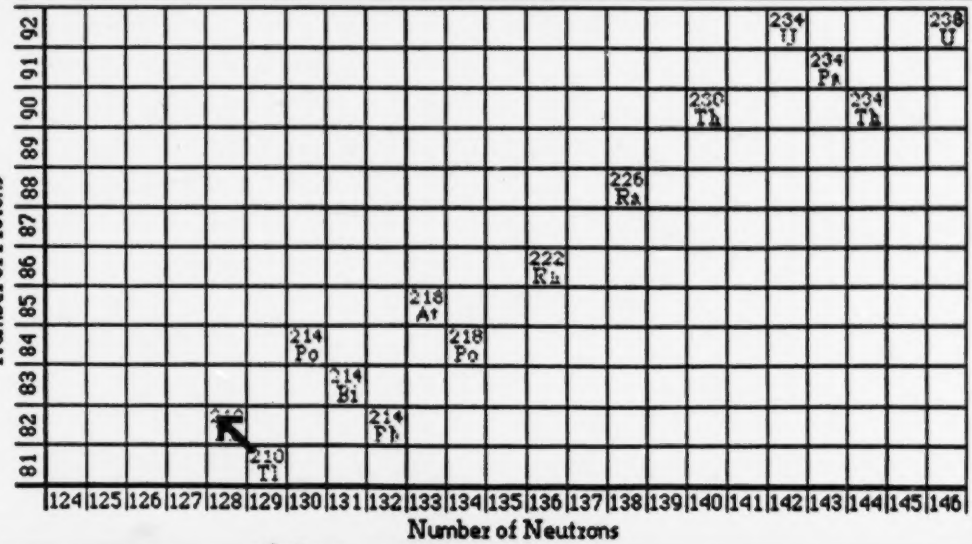
Tl210

β⁻

Pb210

Beta Particle

electron
small
medium LET



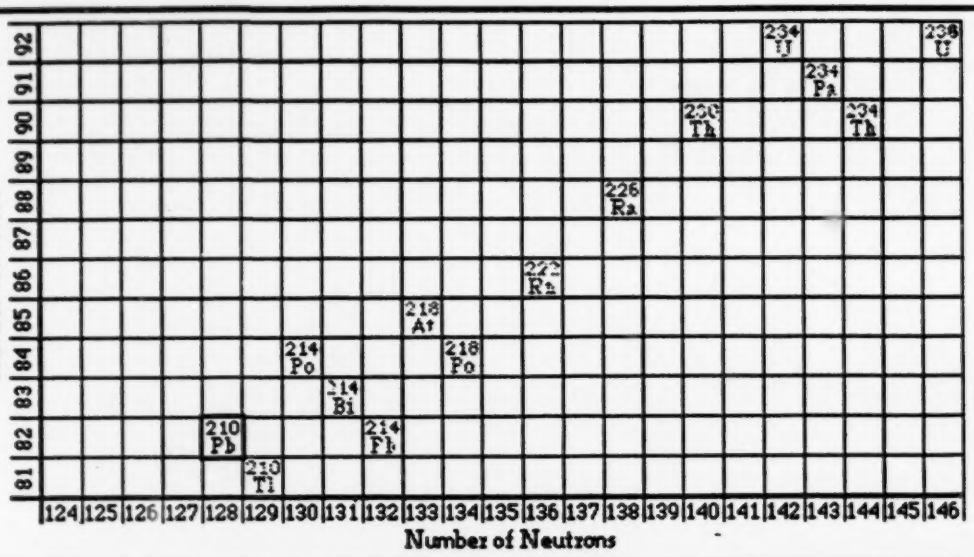
30

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Lead-210

Pb210
22.3 y
β⁻ to Bi210

Solid
dust to lungs
causes cancer



31

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Beta Decay

β⁻ out

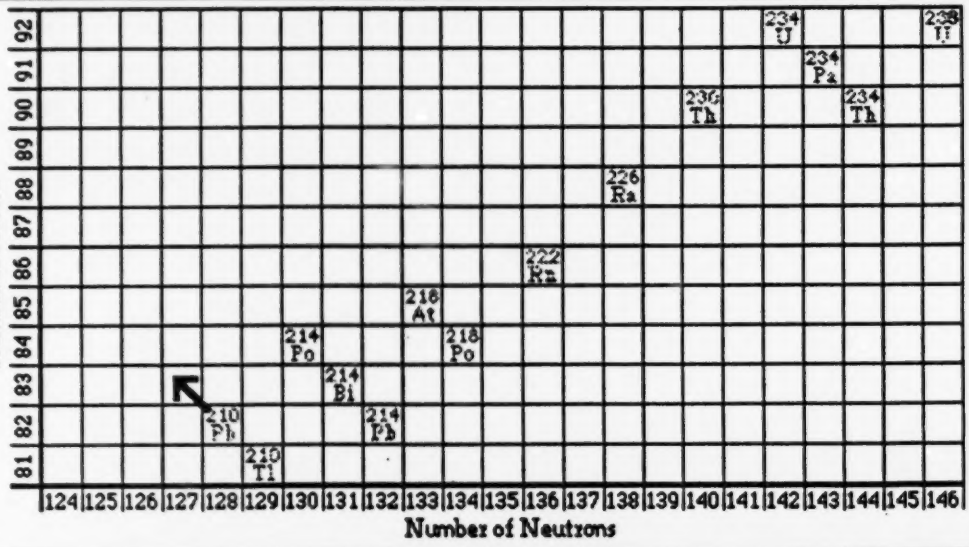
Pb210

β⁻

Bi210

Beta Particle

electron
small
medium LET

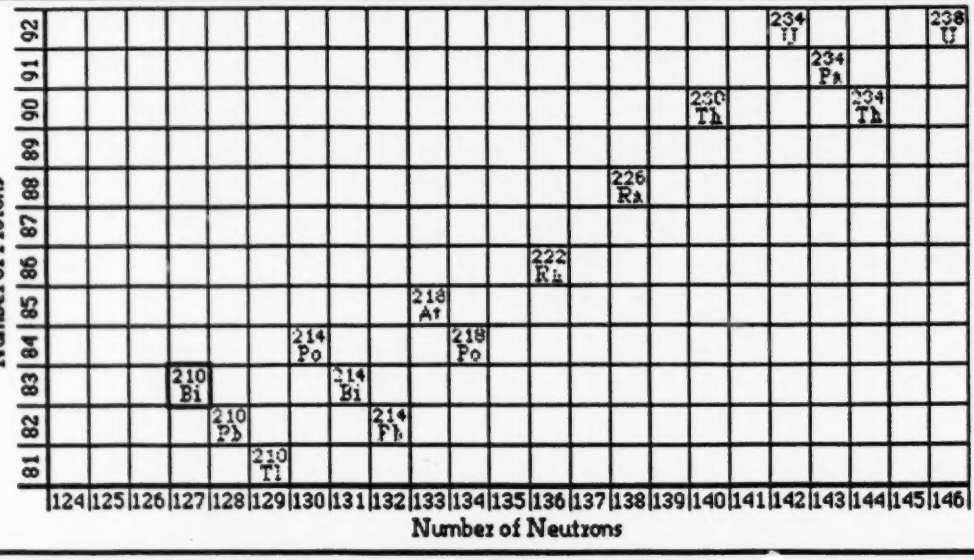


32

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Bismuth-210

Bi210
3.0E6 y
α to Tl206
β to Po210



33

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Beta Decay

β⁻ out

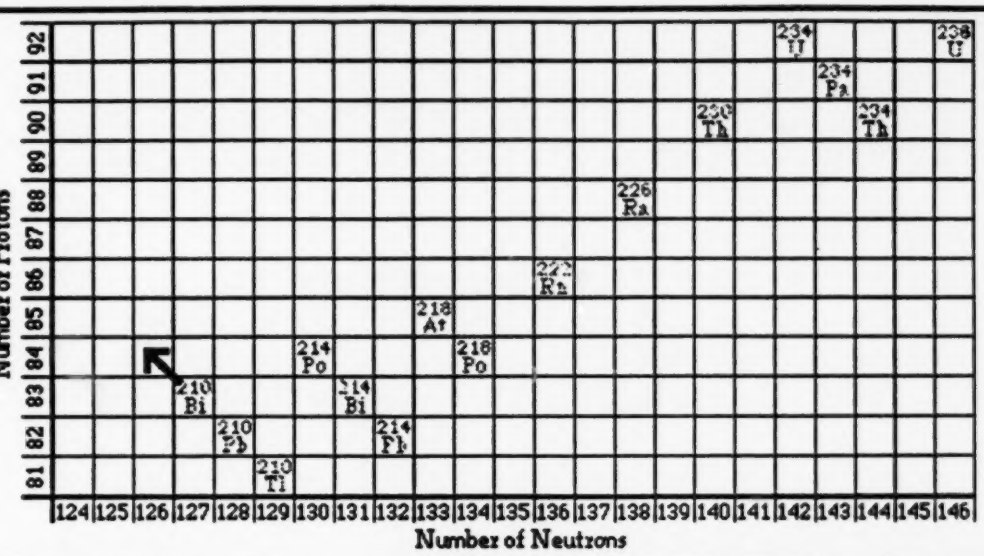
Bi210

β⁻

Po210

Beta Particle

electron
small
medium LET



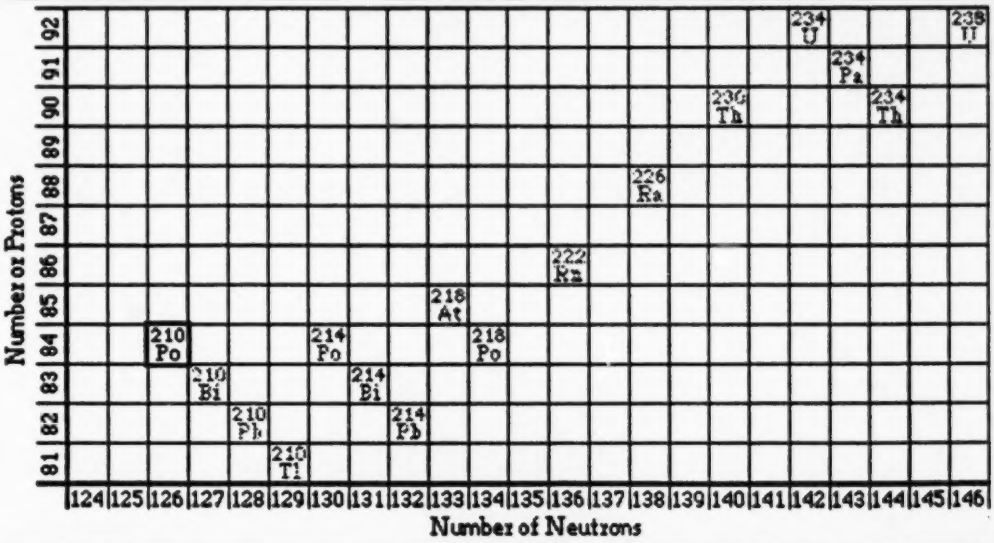
34

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Polonium-210

Po210
138.38 d
α to Pb206

Reduces
static on
film & records



35

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Alpha Decay

α out

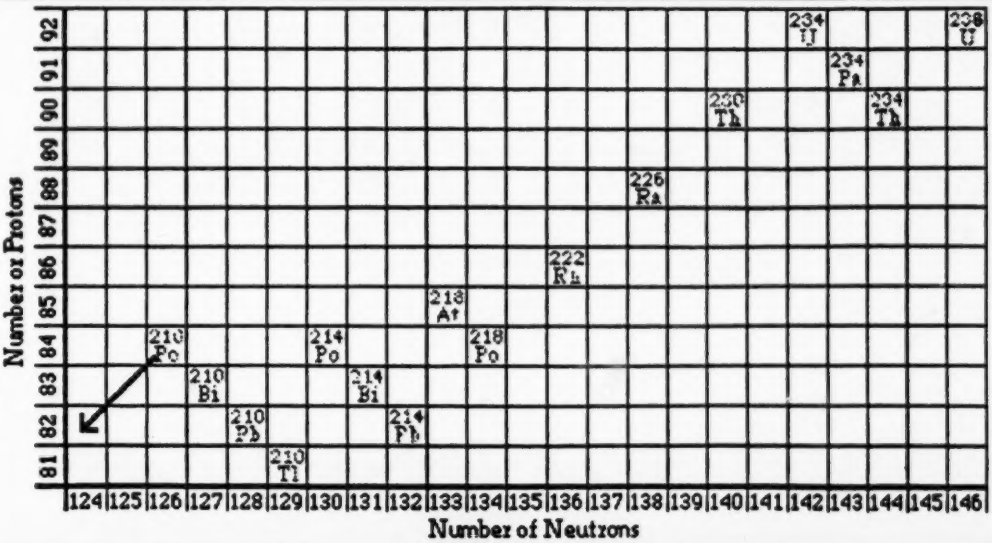
Po210

α

Pb206

Alpha Paticle

large, massive
2p 2n
He nucleus
high LET



36

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Lead-206

Pb206
no decay

Stable
Natural
End
Product of
Uranium Decay

37

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Alpha Decay

α out

Bi210

α

Tl206

Alpha Paticle
large, massive
2p 2n
He nucleus
high LET

38

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Thallium-206

Tl206
3.76 m
β⁻ to Pb206

39

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Beta Decay

β⁻ out

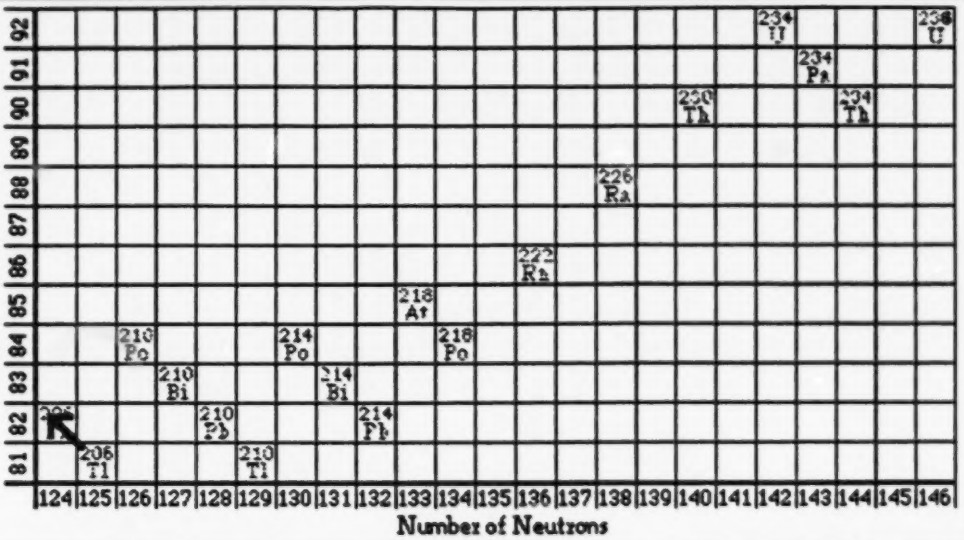
Tl206

β⁻

Pb206

Beta Particle

electron
small
medium LET



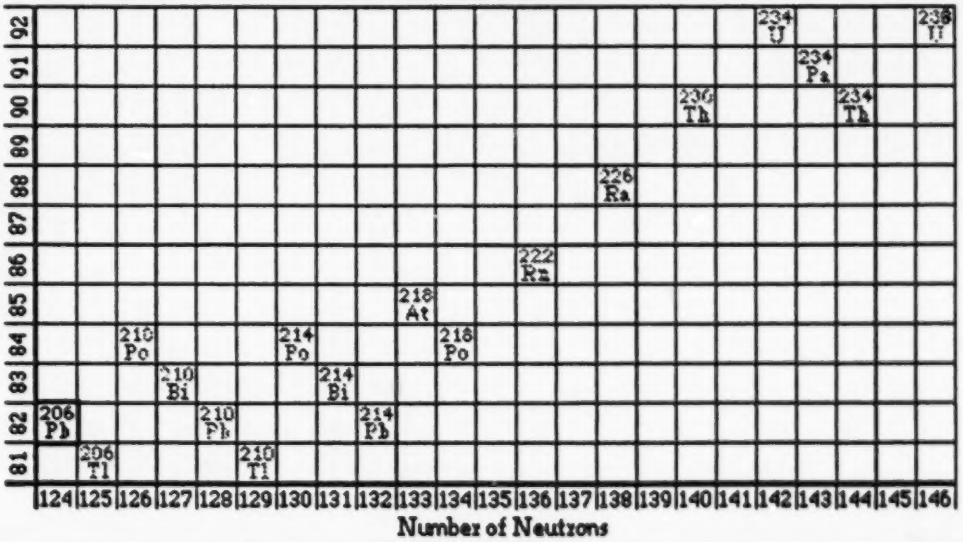
40

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Lead-206

Pb206
no decay

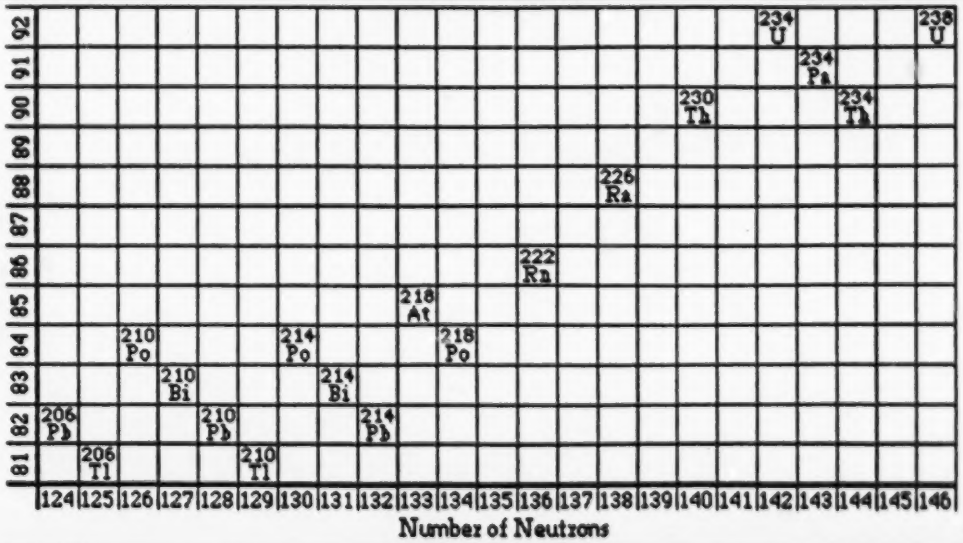
Stable
Natural
End
Product of
Uranium Decay



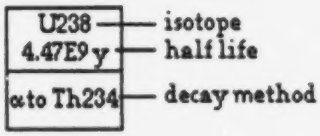
41

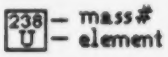
Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Isotopes
formed
by the
natural
radioactive
decay of
Uranium-238
and their
positions
on the
Chart
of the
Nuclides



42





TIME

μs microseconds
s seconds
m minutes
d days
y years

SYMBOLS

α alpha particle
β^- negative electron or Beta particle
E exponent ex: E9 = 10^9
p proton
n neutron
LET linear energy transfer

Alpha decay or loss of 1p & 1n

Beta decay or loss of electron

Questions:

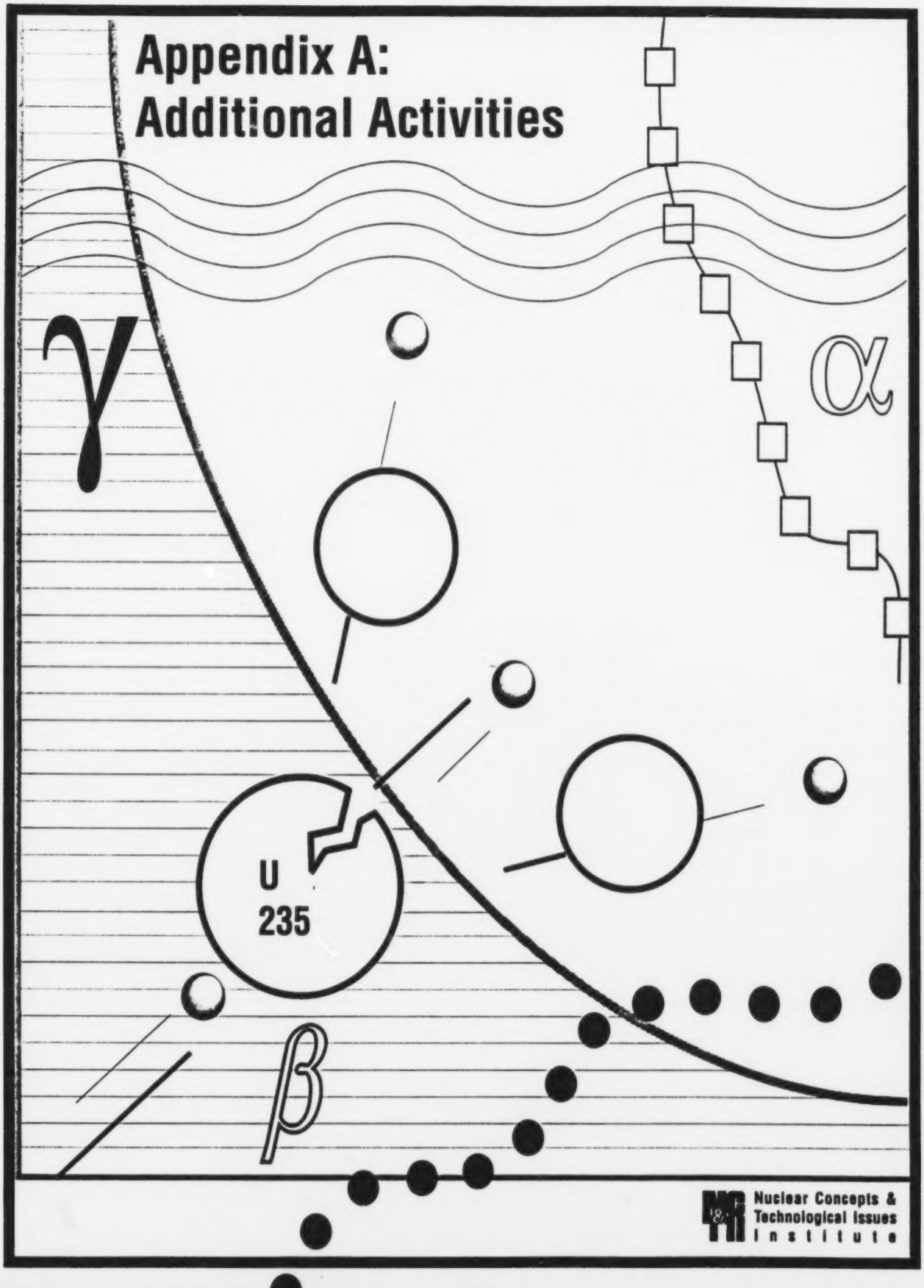
1. In which direction and in how many steps does an alpha decay proceed on the Chart of the Nuclides?
2. In which direction and in how many steps does a beta decay proceed on the Chart of the Nuclides?
3. Why does the decay sequence work its way to the lower left corner of of the chart?
4. What happens to mass #, protons and # of neturons in an alpha decay and in a beta decay?
5. What progeny of Bi210 is from alpha decay?
6. What progeny of Bi210 is from beta decay?
7. Which progeny in the U238 decay is a gas?
8. What is the half life of this gaseous isotope?
9. Why is the gaseous nature of this isotope an environomental problem?
10. Which decay particle has the greatest linear energy transfer LET?
11. What effect might this have for radon progeny?
12. List the progeny of radon.
13. Write an equation for the Uranium-238 decay chain.
14. Identify several useful isotopes and explain their uses.
15. Write the equation for another decay chain which would be appropriate for another flip book.

Flip Book Chart of the Nuclides
The Uranium-238 Decay Chain
by Michael Szesze

Instructions for Assembling the Flip Book Chart of the Nuclides

1. Cut out all of the cards (1-45) and place them in a stack with 1 on top.
2. Tap the stack on its side so that all cards are flush with the right side.
3. Staple the left side of the flip book together with two or three stables.
4. Hold the flip book in the left hand with your thumb and finger tips.
5. Use your right thumb and fingers to leaf through the pages and see the animation.

Appendix A:
Additional Activities



Nuclear Concepts & Technological Issues Institute

Radiation Hunt

Purpose: This simple activity enables students to determine that some natural and manmade materials are radioactive while other similar looking ones are not. It serves as an introduction to the concepts of background and low level radiation. The activity is suitable for elementary school students as well as older students.

Materials: Geiger counter(s), Radioactivity Worksheets, and pencils

Select as many as desired from among the following:

Sealed alpha, beta and gamma sources

Old Fiesta ware dishes (various colors, including deep orange, which contains uranium compounds)

Old Coleman lantern mantles (contain thorium which is radioactive)

Smoke detector (contains americium)

Uranium ore samples

Old glow-in-the-dark dial wrist watch (contains radium)

Weighted (sand filled) cellophane tape dispenser (sand often contains thorium)

Materials that have been processed with radiation, but aren't radioactive, e.g.: Perma-grain wood, non-stick pan, shrink wrap, X-ray, sterilized surgical gloves or sponges, etc.

Sources of light (flashlights, lamps, etc.) which is non-ionizing radiation

Assorted non-radioactive materials, similar to items above, e.g., rocks and pebbles, modern dishes, modern wrist watches, etc.

Procedure:

1. Students turn on Geiger counters. (Work in groups, if necessary.)

    a. What happens when the Geiger counter is turned on?

    b. What is background radiation? Where does it come from?

2. Students test different materials with the Geiger counter, and record their findings on the Radioactivity Worksheet as very radioactive, slightly radioactive, or not radioactive (background only).

3. (Optional) Students compare their findings by having each group copy their results on a large chart mounted on a bulletin board.

Discussion and Research Questions:

1. What is radiation?

2. What does it mean when we say something is radioactive?

3. Does a Geiger counter detect all kinds of radiation?

4. Exactly what kinds of radiation does a Geiger counter detect?

5. How does a Geiger counter work?

6. If a non-radioactive material is exposed to radiation, does it become radioactive?

7. What is meant by ionizing and non-ionizing radiation? What are three types of ionizing radiation?

Radioactivity Worksheet

Please test each item for radioactivity using the Geiger counter. Check the appropriate column for each item tested.

ITEM	BACKGROUND	SLIGHTLY	VERY

M & M Half Life

Background: Half life is the time required for one half of a radioactive material to decay or change into something else. Radioactive atoms have nuclei that are unstable. By emitting particles or rays these nuclei become more stable. The half life of an isotope is a physical property. The value can be from fractions of a second to billions of years. Half life values are constant - there is no way to speed up or slow down this natural process.

Introduction: This activity is an enjoyable simulation of the process of radioactive decay, suitable for junior high and some senior high science classes. You may wish to permit the students to eat the "atoms" that have "decayed" to a stable state . If so, be sure that students have washed their hands before starting the experiment and that they don't drop any of the "atoms" on the floor!

Materials: Plastic bag containing at least 50 M & M candies, for each group

Paper plate

Data table and graph paper

pencil

Procedure: 1. Shake up the "radioactive atoms" (the M & Ms) in the sealed bag, and then pour them all out into the paper plate. Those M & Ms with the letters showing are still "radioactive" whereas those without the letters showing have decayed to a stable state.

2. Count and record the total number of M & Ms. Count and record the number that have decayed to a stable state. Remove the decayed atoms and set aside.

3. Return the still radioactive atoms to the plastic bag, seal it and shake it up well. Pour out the M & Ms onto the paper plate. Again count and record the number of the atoms that have decayed (no letters showing), remove them and return the still radioactive atoms to the plastic bag. Repeat the procedure until all the radioactive atoms have decayed.

4. Fill in the data table and plot the data on graph paper, using the "Y" axis for the number of radioactive atoms remaining and the "X" axis for the number of the trial. Draw a smooth curve through the data points.

Analysis: To find the value for the half life:

1. Select two values on the "y" axis. One value should be twice as large as the other (60 and 30, for example).

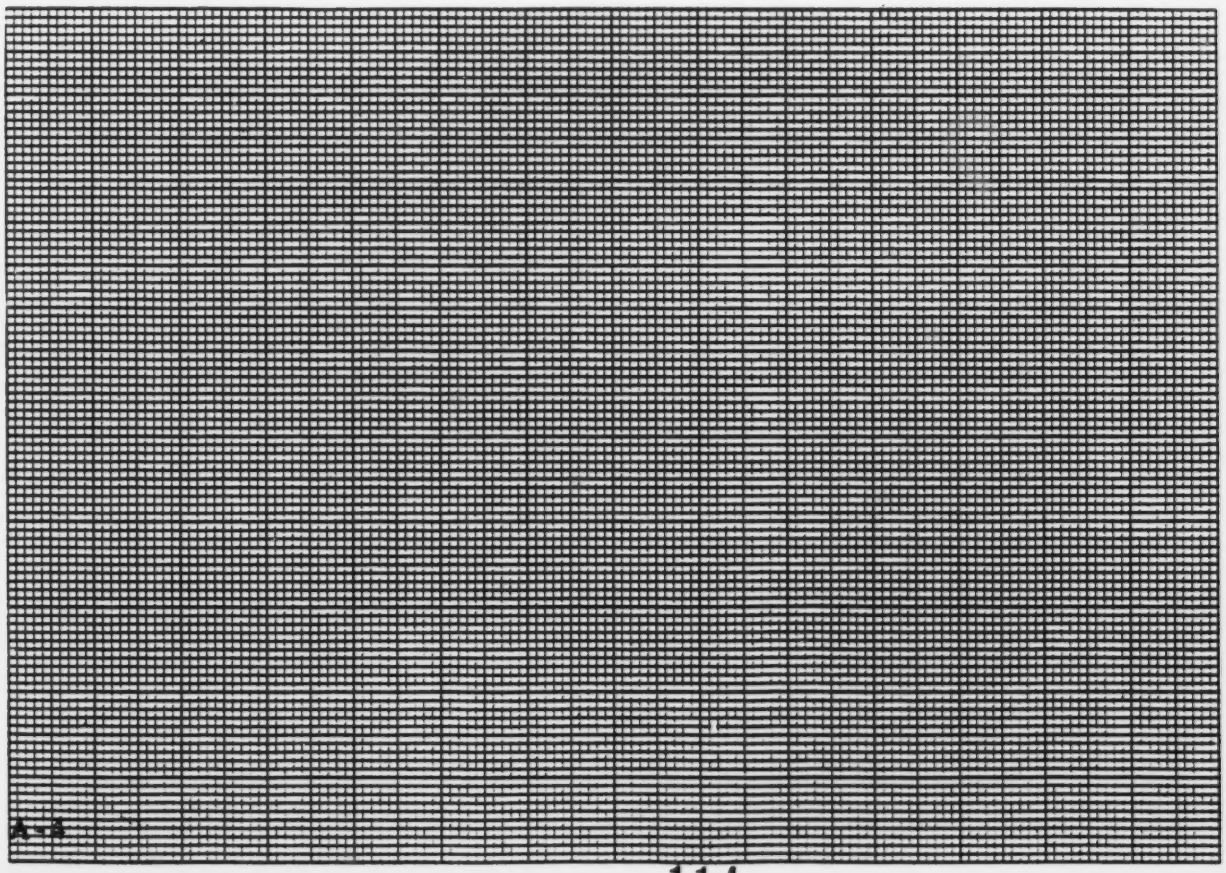
2. Draw horizontal lines from these points to your curve.

3. Next, draw vertical lines from the points where the lines intersect your curve down to the "x" axis. The space between these lines on the "x" axis represents the half life, or the amount of time needed for half of the radioactive atoms to decay.

Data Sheet and Graph

Original number of atoms (M & Ms): _____

Trial	Atoms Left	Atoms Decayed
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		



Licorice Half Life

by Tim DeVries

Introduction: This activity is a simple and enjoyable introduction to the concept of half life suitable for middle school and junior high science classes.

Materials: One piece of "shoe lace" licorice per student or group of two
Graph paper with X and Y axes labelled as shown on next page
Pencil

Procedure: 1. Place piece of licorice on graph paper and stretch it full length up and down over the time zero mark. With a pencil mark the graph paper at the top of the licorice. This mark represents 100% of the licorice, so write 100 on the Y axis (% of licorice remaining) at the same height as the licorice.

2. When the teacher says "GO", you will have ten seconds to bite off and eat exactly half of your licorice. Then place the remaining licorice over the ten second line and mark the height of the licorice on your graph. Also write 50 at the correct place on the Y axis.

3. At time twenty seconds your teacher will again say "GO", and you should bite off and eat half of the licorice that was left. Place the remaining licorice over the twenty second line and mark the height of the remaining licorice. Then write 25 at the correct place on the Y axis.

4. Continue the procedure as directed by your teacher until ninety seconds have gone by.

5. Connect all the height marks with a line between each ten second interval mark, completing the graph of the "half life" of licorice.

Questions: 1. Did the licorice ever completely disappear or did it just get so small that you couldn't bite it into halves?

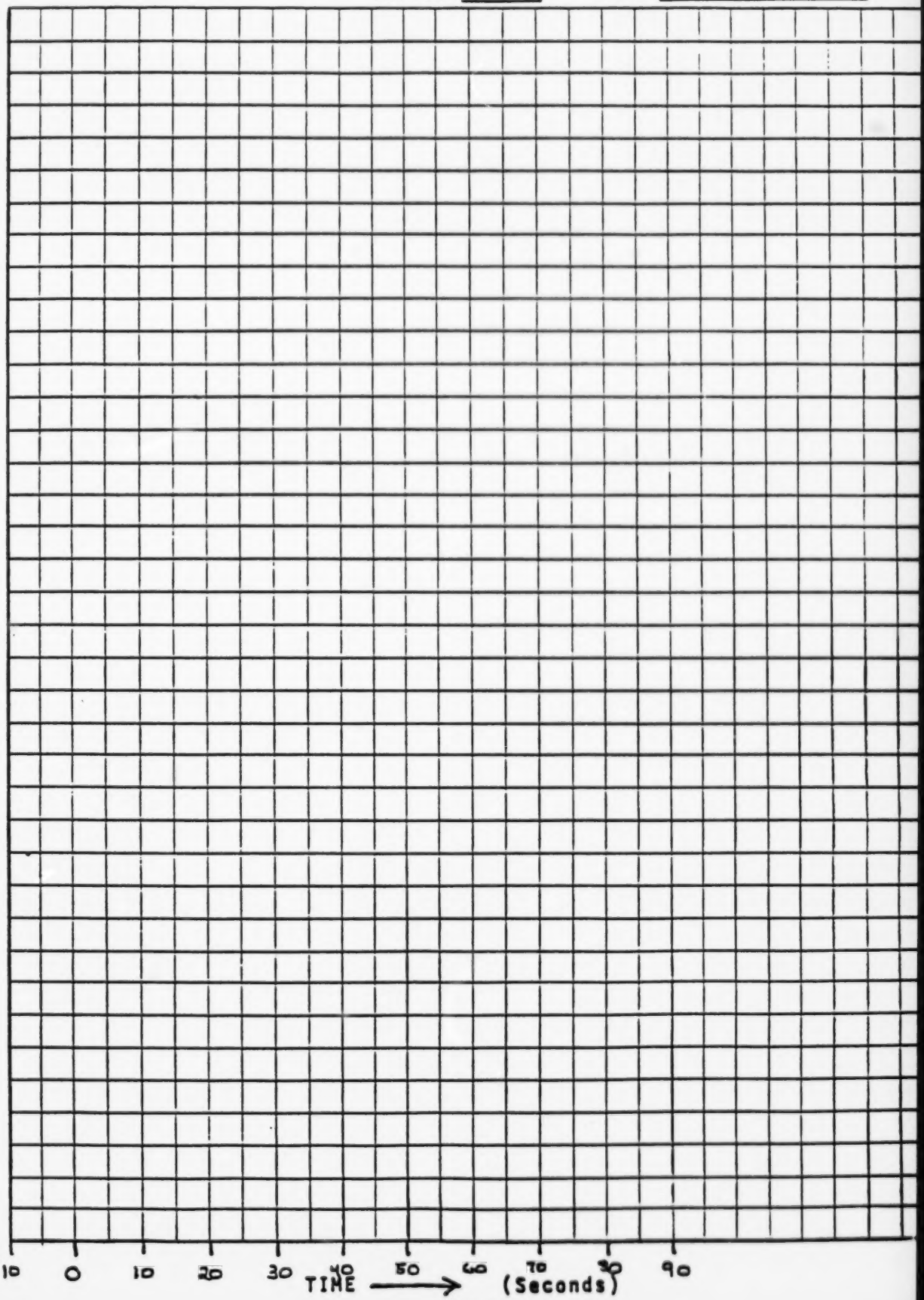
2. If the entire earth could be divided in half, and then in half again over and over like the piece of licorice for as long as you could, what would be the smallest piece you would end up with?

3. If you had started with a piece of licorice that was twice as long, would it have made any difference in the graph line you would have obtained? To try this, look back to a time minus(-) 10 seconds and imagine how tall the licorice would have been then. What really does change when you use more licorice?

4. Suppose that you now start with the tiny bit of licorice at 90 seconds. Now suppose you doubled its length (height) every 10 seconds as you moved to the left on your graph toward zero seconds. At zero seconds, of course, you'd have reached the size of one piece of licorice. What would be the size of the piece of licorice at minus(-) 40 seconds?

5. Using the same method as in question 4, continue doubling the length of the licorice until you reach minus (-) 100 seconds. How long a piece would you have then?

Period:_____ Date:_____



A-6

6. Believe it or not, by the time you reached minus(-) 1,000 seconds the licorice would outweigh the earth! So if you started with a piece of licorice long enough to rolled in to a ball that outweighed the earth, and followed the procedure of the experiment, cutting it in half once every ten seconds, when would you have a piece so small you couldn't bite it in half again? Try putting your answer into minutes.

7. Does it really matter how large a sample you start with for this graph? Why or why not?

8. In the activity you just completed the time span of ten seconds is called the half life of the licorice. Why is half life a good name for that?

Using What You've Learned:

1. Describe how a graph would be different if you took another piece of licorice exactly the same size as the original piece but now you bit it in half and marked its length on the graph every 30 seconds instead of every 10 seconds. What would be the half life of this piece of licorice?

2. The population of the earth is doubling every 40 years. If the earth's population is now approximately 6 billion people, what will be the approximate population of the earth when you are 95 years old?

re-actions

Volume 5
September 1989

From the American Nuclear Society to teachers interested in the nuclear sciences.

Demonstration shows how radiation is measured

(In this first issue of the new school year, we offer this special classroom demonstration for high school level, developed by Candace C. Davison, Energy Technology Projects at The Pennsylvania State University. The idea for this demonstration originated with Kenneth L. Miller, Milton S. Hershey Medical Center.)

Radiation workers need a means to detect their exposure to ionizing radiation. Ionizing radiation creates charged particles (ions) as it travels through matter. One way to measure exposure to ionizing radiation is through the use of thermoluminescent dosimeters (TLD). Thermoluminescent dosimeters are materials, typically crystals such as lithium fluoride, that "store" energy deposited by ionizing radiation.

To release the "stored" energy, the material must be heated to high temperatures. This stored energy is then released as light. To determine the amount of energy stored by the material, the amount of light released is measured with a light sensitive instrument such as a photomultiplier tube. The amount of light that is emitted when the material is heated corresponds to the energy deposited in the material. This information can then be used to calculate a person's exposure to ionizing radiation.

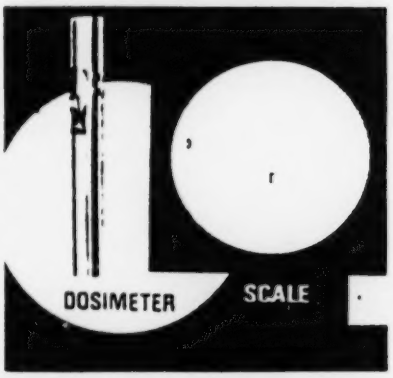
It is important to note that light (nonionizing radiation) is released. Ionizing radiation was not "stored" in the material—only the energy that was deposited in the material as the ionizing radiation passed through. Another interesting note: This technique has been suggested to help determine the energy deposited by atomic bombs. By taking samples of ceramic tiles used in rooftops and applying the above principles, the deposited energy can be determined at different distances.

The demonstration

To demonstrate the energy stored in a crystal, materials needed are:

- Table salt (NaCl) exposed to at least 180,000 rads of gamma radiation (see source below)
- A hot plate or heating element with a flat surface
- A dark room

Background: By exposing table salt to gamma rays (gamma rays are ionizing radiation similar to X rays) a demonstration can show how a thermoluminescent dosimeter works. While sodium chloride (NaCl) is not as sensitive to ionizing radiation as lithium fluoride and other materials used for TLDs, it is more easily obtained, less expensive, and easy to work with. The salt needs to be exposed to a very high dose of ionizing radiation (at least 180,000 rads of gamma radiation).



One type of dosimeter is shown at left.

After the salt has been exposed to the radiation, its color changes due to the way that energy is stored in the salt crystal. When ionizing radiation passes through the salt, the energy deposited excites electrons. The excited electron is moved up to a higher energy state. The reason the salt is a different color is that these displaced electrons affect the way light is reflected by the crystal, thus a color appears.

In order to release the energy trapped by the electron in the crystal, the salt needs to be heated. When the salt is heated, the electrons can return to their original positions and, in the process, release energy. This energy is in the form of visible light. Notice that the salt returns to its original white color after it has been heated and has released all of its energy.

Procedure: For best results, turn on the hot plate (high—375F or higher) and darken the room (the darker the better). Throw some of the irradiated salt onto the preheated hot plate. Watch what happens! To obtain irradiated salt for this demonstration, send a ~~$10 check payable to~~ The Pennsylvania State University to: Penn State Breazeale Reactor, University Park, PA 16802; 814/865-6351. Request: irradiated salt. *See Note on Back

Discussion questions

After the salt has been exposed to ionizing radiation, is it radioactive? No. The energy deposited by the ionizing radiation is stored in the salt, but the salt is *not* radioactive—just as people are not radioactive after they have been exposed to ionizing radiation from X rays. This can be demonstrated by using a geiger counter and testing the salt before and after it has been irradiated. To understand how energy that is stored can be released, think of the chemical energy stored in wood or coal, and how that energy is released when those fuels are burned.

What happens to the salt when it is heated? Light is released. The heat allows the electrons that were trapped in the crystal structure (when the energy was deposited) to return to their original positions. Since this original position was at a lower energy state, the difference in energy between the high energy state (where the electron was trapped) and the low energy state (the original position where the electron returns) is released as a packet of energy. This packet of energy is a photon of visible light.

Why does the salt change color? The color of an object is determined by the way light interacts with that object. Since electrons are trapped in a different position in the crystal, light is absorbed and reflected (filtered) in a different manner than when the elec-

Continued on page 4

NUCLEAR SCIENCES

onto the floor, count it as a "miss." If a straw misses the cardboard, don't count it at all. Continue throwing until there are at least 20 or 30 hits. The greater the number of hits and misses, the greater the chance for significant results. Be sure to record both hits and misses.

Calculate the total area of the holes by following this formula:

$$\frac{\text{Area of holes}}{\text{Area of cardboard}} = \frac{\text{Hits}}{\text{Misses}}, \text{ or use}$$

$$\text{Area of holes} = \frac{\text{Hits}}{\text{Hits} + \text{Misses}} \times \text{Area of cardboard}$$

Divide by five to get the *experimental area* of one hole. Measure a hole with a ruler. From this information figure out the actual area and compare the figure with the experimental area. The area of a circle is equal to the radius times the radius times pi (3.14). Using this formula, the area of the cardboard would be 12 inches × 12 inches × 3.14 or 452.16 square inches. The area of the measured hole can be figured out from the radius in the same way.

Some students may try to cancel hits in the numerator and denominator of the formula. This can't be done. You also may notice that some students feel a high number of hits is important and tend to call questionable tosses "hits." *Question:* Can students explain which parts of their experiment correlate to the gold foil (cardboard), nuclei of atoms (holes), fluorescent screen (box), protons (straws), and device producing protons (students)?

(OVER)

Important dates

NUCLEAR SCIENCES

American Nuclear Society

Classroom project #22—Rutherford's experiment

In 1911, Ernest Rutherford discovered that the atom is mostly space with a small massive center or nucleus. One way to explain Rutherford's experiment is: A small piece of very thin, gold foil is measured accurately. From certain rules of science, this measurement can be used to tell the number of atoms in the foil. The foil is then placed in front of a fluorescent screen. A device is placed on the other side of the foil which produces a stream of protons. When the protons strike the screen, a small part of the screen glows. If a proton comes close to the nucleus, the positive charge of the nucleus repels the positive proton. Most of the protons pass through the foil without being greatly affected by the nuclei. The screen shows a few protons are thrown off course by being repelled.

In the following activity, students use an indirect method to measure the area of holes—similar to Rutherford's method of measuring the nucleus. The experiment works very well with a large group; all students have a chance to participate.

Procedure: Cut a two-foot diameter circle from cardboard. Cut five equal-sized holes in the circle, spacing the holes as evenly as possible. The holes should be about two inches in diameter—estimate, don't measure at this time. Place the cardboard over a box or wastebasket. Place a chair about six feet from the box. Cut soda straws into pieces about ¼-inch long. Sit in the chair and throw the soda straw pieces at the cardboard. If a piece of straw goes directly in one of the holes, count this as a "hit." If a piece of straw strikes the cardboard first before going into a hole or

(OVER)

physical and social sciences, for middle and high school teachers, sponsored by ANS Oak Ridge/Knoxville Section, at the Garden Plaza Hotel, Oak Ridge, TN. Three

to tie in nuclear science, chemistry, and energy activities at the end of Energy Awareness Month!

November 10-13: National Council for the Social Studies Meeting,

DEMONSTRATION

Continued from page 1

trons are in their original positions. When electrons return to their original positions (after the salt has been heated) there is no interference with the way light interacts with the crystal and the salt becomes white again. (This technique also is used to artificially change the color of gems, including some diamonds.)

*NOTE: 1994 price is $12.50 per bottle. Purchase Orders or Invoices must be a minimum of $25.00

In history

October 1974: Fifteen years ago, legislation to split the Atomic Energy Commission into an Energy Research and Development Administration and a Nuclear Regulatory Commission cleared the House, the Senate, conference committee, and the President's desk.

1964: Twenty-five years ago, the U.S. Food and Drug Administration approved irradiation for sprout inhibition of white potatoes.

October 3, 1964: Twenty-five years ago, the nuclear-powered surface ships *Enterprise*, *Long Beach*, and *Bainbridge* completed "Operation Sea Orbit," an around-the-world cruise without logistic support of any kind.

ANS museum exhibit showings

Now-October 1: Evansville (IN) Museum of Arts and Science/Koch Science Center and Planetarium ("Our Radioactive World").

Now-November 3: Omniplex, Oklahoma City, OK ("Uranium + Water: Electricity").

Now-November 30: National Atomic Museum, Albuquerque, NM ("The Atom in Everyday Life").

October 15-December 31: Everhart Museum, Scranton, PA ("Our Radioactive World").

November 20-February 15, 1990: Discovery Center, Amarillo, TX ("Uranium + Water: Electricity").

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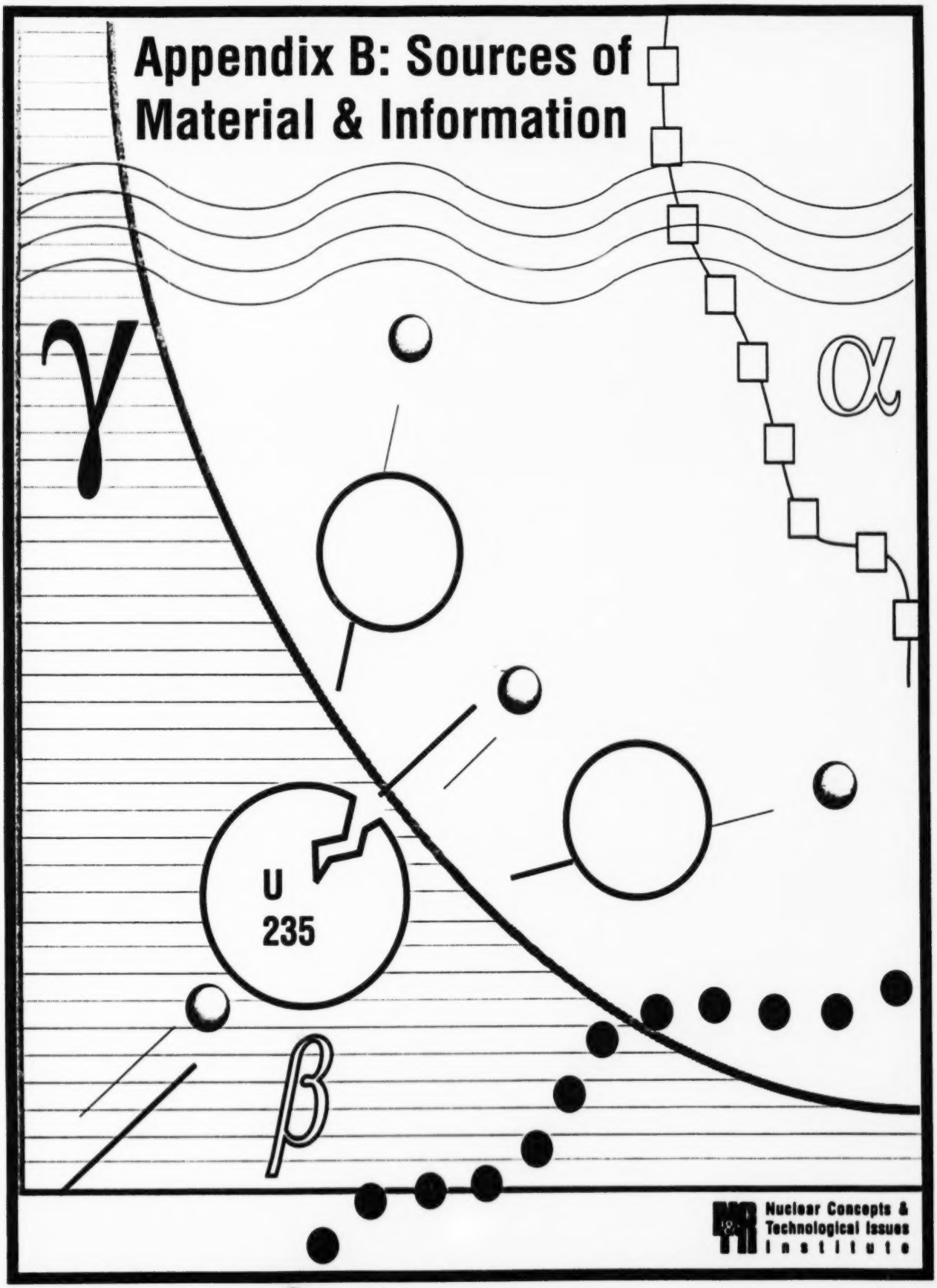
Re-Actions is published by the ANS Outreach Department for educators interested in learning and teaching about the various peaceful uses of nuclear science and careers in this field. This newsletter also is sent to ANS local sections and student branches to encourage a "re-action"-a relationship- between ANS members and teachers in their locales.

Teacher names are welcome for addition to the reactions mailing list. Any communication dealing with this publication should be addressed to re-actions Editorial staff, ANS, 555 N. Kensington Ave., La Grange Park, IL 60526; telephone 708/579-8251; e-mail outreach@ans.org

Appendix B: Sources of Material & Information



Nuclear Concepts & Technological Issues Institute

Sources of Materials and Information

Equipment Sources*

1. Cloud Chambers are available as a set of 5 with instructions for approximately $30 from:

   Hubbard - Redco
   P. O. Box 760
   Chippena Falls, WI 54729

2. Sealed Radioactive Sources - For license-exempt quantities of sealed alpha, beta and gamma sources, contact:

   Oxford, Inc.
   601 Oak Ridge Turnpike
   Oak Ridge, TN 37830
   (615) 483-8405

3. The Radioactivity Game including game board template and instructions plus a booklet of activities as well as a supplement. Ask for Nuclear Energy Student Activities, price - approximately $4

   New York STS Education Project
   89 Washington Avenue
   Room 678, EBA
   Albany, NY 12234

4. Geiger Counters under $200.00

   Frey Scientific
   800-225-3739 Item #F-13749

   Sargent Welch
   800-SARGENT Item #S72096-05

   CENCO
   800-262 3626 Item #33025

5. Geiger detectors that interface with computers

   AWARE electronics (302) 655-3800
   IBM interface (telephone cord link to computer)
   RM-60 small tube
   RM-70 larger tube

   Vernier - (503) 297-5317
   Universal Lab Interface needed-(Apple/IBM/Mac)
   Radiation Monitor sold separately

PASCO - 800-772-8700
Introductory Computer GM System (Apple/IBM)

OXFORD Instruments - (formerly the Nucleus) - (615) 483-8405
GMX- Interface (Geiger system for Apple/IBM/Mac) includes GM-probe, module and software that can automatically take readings, plot data for at least 5 different experiments

PCA card (need NaI detector for multichannel analyzer capability) - Apple or IBM

Radon Gas determination - Oxford instruments also has a stand-alone student scalar

SPECTECH - (615)482-9937
Ratemeter with Data Link
Radiation Counter with Data Link

*Not responsible for current prices: check with the manufacturer. This is only a partial list and not meant to be comprehensive. No endorsement of equipment or a particular company is intended.

Information Sources**

1. General Electric Company
Nuclear Energy Operations
175 Curtner Avenue, M/C 397
San Jose, CA 95125

The Chart of the Nuclides is available in a soft bound book entitled Nuclides and Isotopes, Fourteenth Edition, Chart of the Nuclides for approximately $10. Also available is a very large wall chart for approximately $10 - $20.

2. Penn State University
Energy Technology Projects
University Support Bldg. I, Suite B
820 N. University Drive
University Park, PA 16802
(814) 863-2133

A. Print and non print educational and informational materials (PA)
B. Educational Programs for teachers/students - summer courses and workshops
C. PELLrad (Public Education on Low Level Radiation) - PA. MD, WV, DE - low level radioactive waste
D. ACURI - Appalachian Compact Users of Radioactive Isotopes

3. Penn State University
Breazeale Nuclear Reactor
University Park, Pa 16802
(814) 865-6351
Contact Candace Davison for information about:

A. Educational programs including radiation experiments and nuclear reactor demonstration for high school science students and teachers
B. Nuclear Concepts summer course for science teachers
C. Research support for college level and science project support for secondary level - irradiation of seeds, fruit flies, and other materials in gamma source (Cobalt-60)
D. RAYS (Radiation Activities for Youth Series) 5-8 grade materials

4. U.S. Dept. of Energy
P.O. Box 62
Oak Ridge, TN 37830

Information and educational materials about energy, such as: "Electricity from Nuclear Power Plants", "Nuclear Fuel Cycle", conservation activities and electricity activities

5. Office of Civilian Radioactive Waste Management (High-level waste)
OCRWM Information Center
P.O. Box 44375
Washington, DC 20026
1-800-225-6972 (in Washington DC call 488-5513)

Curriculum materials entitled "Science, Society and America's Nuclear Waste", a 4-unit set for teachers; student reader sets available for classroom; compilation videotape supporting curriculum; answers to questions concerning high level waste program

6. Nuclear Energy Institute (formerly U.S. Council for Energy Awareness - USCEA)
Publications Department - Suite 400
1776 I Street, NW.
202-739-8000

Technical and non technical publications on such topics as electricity from nuclear power and food irradiation

7. Department of Environmental Resources
Bureau of Radiation Protection
P.O. Box 8469
Harrisburg, PA 17105-8469
1-800-232-2786 (717) 787-2163

Pennsylvania information on such topics as radon and low level radioactive waste. Other states also have state radon offices, usually in the capital city.

8. American Nuclear Society
Public Communications Department
555 N. Kensington Avenue
La Grange Park, IL 60525
(708) 579-8201

A. Re-Actions Newsletter with information about nuclear science and classroom applications
B. Curriculum materials
C. Audiovisuals
D. Information about applications of the atom, e.g.,
1. Bibliography of Quotes on Peaceful Uses of the Atom and Radioactive Substances
2. How Can the Atom Be Used to Benefit Our Daily Lives?

9. Health Physics Society
Chair of the Committee on Manpower and Professional Education
c/o Office of Executive Secretary
1340 Old Chain Bridge Rd., Suite 300
McLean, VA 22101

Information on nuclear medicine, health effects of radiation, etc.

10. The Society of Nuclear Medicine
136 Madison Avenue
New York, NY 10016-6760
(212) 889-0717 Fax: 212-545-0221

Information on careers in nuclear medicine and technology

11. Electric Power Research Institute
2000 L Street, NW
Suite 805, 8th Floor
Washington, DC 20036
(202) 872-9222
Fax: 202-293-2697

3412 Hillview Avenue
Palo Alto, CA 94304
(415) 855-2000
Fax: 415-855-2954

Information on generation, delivery, and use of electricity, with special attention to cost-effectiveness and environmental acceptability

**This list is partial only and is not meant to be comprehensive.

American Nuclear Science Teachers Association

The American Nuclear Science Teachers Association is a professional educational society for those interested in the teaching of radiation and its applications in everyday life. ANSTA recognizes the importance of nuclear science and technology in today's world, and firmly believes that an in-depth understanding of the facts concerning nuclear science is essential in forming rational decisions concerning its application.

ANSTA is for educators at all grade levels interested in energy, radiation, nuclear technology, radioactive waste disposal and nuclear career opportunities.

ANSTA is dedicated to promoting nuclear science education, and providing teachers with opportunities to share teaching experiences and to acquire information about new developments in nuclear theory and technology.

ANSTA is an organization of teachers, for teachers. Through affiliation with the American Nuclear Society, ANSTA also makes publications and meetings of that organization available to its members.

ANSTA Membership Application Form

Dues cover the period of June 1 through May 31

Membership Classification

1. Regular Membership - Teachers or former teachers who have an interest in Nuclear Science Education

2. Affiliate Membership - Others who have an interest in nuclear science education

3. Supportive Membership - Firms, Organizations or others that wish to promote nuclear science education and support ANSTA outreach activities

Name _____

Title _____

Address _____

_____

Telephone
Daytime _____
Evening _____

Please check one:

❑ Regular or ❑ Affiliate membership - $10.00 per year

❑ Regular or ❑ Affiliate membership - $25.00 for 3 years

❑ Supportive membership - Minimum of $100 annual dues

Please check the area(s) of your interest for materials and information

❑ Elementary ❑ High School
❑ Middle school ❑ College/Univ.

Send this completed application and a check payable to ANSTA to:

ANSTA Treasurer
c/o American Nuclear Society
555 N. Kensington Ave.
La Grange Park, IL 60525
telephone: 708-579-8251

This form may be photocopied

This publication is available in alternative media on request.

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